# A SURVEY COURSE IN GENERAL BIOLOGY

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# A SURVEY COURSE IN GENERAL BIOLOGY

BY

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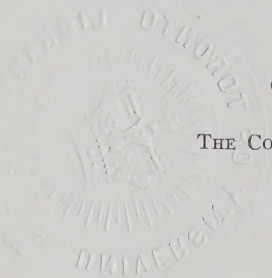

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To

THE MEMORY OF

A GREAT TEACHER

ALBERT HURD

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# PREFACE

THIS is a short introductory course for general students. Out of the embarrassing riches of the vast field of biology I have endeavored to select a few of the things that every one should know in order to understand his own relations with the world of life.

This course is planned primarily for those who are not specializing in biology, but it will serve those who later may specialize equally well by giving on first approach a comprehensive view of the entire field.

We are organisms; and out of that fact grow the fundamental relations that general biology bears to a whole wide range of special sciences, the threshold of which may, I hope, be reached by those who follow the course here outlined.

I have not included specific laboratory directions for the examination of specimens. Most teachers prefer to use their own. But I have described the things that the student should see, in about the order of a natural and convenient approach, with hints here and there as to how they may best be seen; and I believe that the student of average human inquisitiveness will want to see them for himself. Without other directions, specimens may be examined with the text for guidance. It goes scarcely beyond what the student may see and handle. Controversial matters, structures so recondite that he cannot see them, and theories for which he can have no adequate evidence do not seem to me to be a proper part of an introductory course. They may cultivate credulity rather than scientific method.

I deem the laboratory indispensable. I recommend the fullest possible use of living materials in it. Pictures and preserved specimens and slides are indispensable, but these alone will not provide a satisfactory introduction to this study. I do not believe in biology with life left out.

In arrangement of subject matter I stick to the logical order, the true pedagogic order: I proceed from the simple to the complex. There is a logic in the science of biology, clear and definite and significant beyond that of any other science, that is worthy of primary exposition and emphasis.

This book is the lineal descendant of my old *General Biology* that has served a long succession of college students. After the experience of almost a lifetime with the making of a short course for general students, I have made this course still shorter, more limited to essentials, and more indicative of human applications, especially on the intellectual side. And I have used the materials from the old book in so far as they serve my present purpose.

Many excellent young biologists have been my assistants in the conduct of large classes in General Biology at Cornell University. So many of them have helped me and in so many ways that it would be invidious to name a few of them here; but I would gratefully acknowledge my debt to them all. I have had the good fortune to be assisted by those whose purpose it was to help pupils to realize in their own experience the educational values of biology: those who with knowledge and courtesy and sympathy have helped seek out the things that may best be used by elementary students to their own educational profit.

JAMES G. NEEDHAM

ITHACA, N. Y.
March 18, 1932

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# A SURVEY COURSE IN GENERAL BIOLOGY

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THE ANIMAL WORLD

# A SURVEY COURSE IN GENERAL BIOLOGY

## CHAPTER I

## INTRODUCTION

Biology is the science that deals with the life of the world. Of this we are a part. We are living things; and therefore our first reason for studying biology is that we may learn more concerning ourselves. Our bodies have the same needs as those of animals; needs of food and drink, of fresh air and sleep and exercise. We are born and develop and grow old and die much as they do. We share in their behavior.

Biology is a very practical subject; for the life of the world sustains us. It supplies the materials of our livelihood. Our food and clothing are mainly the products of plants and animals. We select a few of the more useful, and by care and culture of them we vastly increase their products. This is the essence of agriculture. This is the means whereby we increase our sustenance and obtain leisure for the development of our arts and sciences.

The life of the world includes our natural enemies. Some are large and frightful like the great beasts of prey. Some are small and insidious, like the microscopic organisms that we know as the germs of disease. By the use of weapons we have overcome the beasts. By scientific investigation we are learning to control the ravage of disease. Here, as everywhere, progress follows upon increase of knowledge. Understanding leads to control.

The science of biology had its far-off beginnings when primitive man started finding out about the plants and animals of his environment. His first quest was probably for things immediately useful: things good for food, or for shelter, or for the making of tools and weapons. But he sought out also other things to cure the ills of his body — medicines; and things that were decorative, for personal adornment; and things that were merely curious and interesting, and therefore gratifying to his inquiring mind.

Plants and animals supply these needs. Both are full of utility, of beauty, and of interest. Learning the ways of plants and animals has ever been a means of personal satisfaction, and of approach to knowledge of the inexhaustible resources of nature.

So, we seek to know. Of all creatures living on this earth we of the human species are the most inquisitive. We share with animals certain states of mind — joy, fear, anger, curiosity, etc., and manifest them by like behavior. We probably do not get more frightened or more angry than some other creatures, but we are far more curious to know about things. Therein lies a difference that in its cumulative results sets us so far apart from other living things as to make us seem like another order of being. This desire to know and to try things is responsible for the development of all our science.

The first of our race to discover and use the resources of the living world were hunters, scouts, and explorers. These men sought out useful wild plants and animals, and began taming them. Men became farmers and herdsmen. They cultivated the plants; they domesticated the animals; and they early performed this service so well that there exist no records of its beginnings. Nearly all the important kinds of plants and animals that we now use were in the service of man before the beginnings of written history.

The oldest biological books are strange mixtures of observed facts and imagined fables. They embody the lore of the ancients. They treat real and imagined plants and animals with equal seriousness. Dragons, unicorns, and sea-serpents romp through their pages quite as do rabbits and hedgehogs and lizards. The first man to organize the existing knowledge thus accumulated was Aristotle. He compared and compiled the ancient records, verified or disproved many of their statements, copied and handed on some of their errors, and organized for the first time our knowledge of natural history. He was a great observer, as well as a great thinker.

His fruitful method of making direct observation and applying reason to the things observed later fell into disuse. Throughout the middle ages there was unbridled speculation and world-shunning. Little was done for the advancement of knowledge until the Renaissance when the spirit of inquiry into the facts of nature revived. It was physicians who first came to the rescue of science. Dealing with the ills of the body, they had need to know about its structure and functions. They restored the habit of fact-finding, and curbed the wild speculations then current as to the causes of disease. Indeed, it is quite so with us personally in our own day; it is the physician who brings us down to earth when we ignore the physical needs of our bodies and treat them with contempt. He makes us realize and respect the limitations of the flesh, that condition and limit the flights of the spirit.

Knowledge of the human body has been obtained in a very large part through the study of the bodies of animals; for they are composed of like parts and have like functions. And they can be used for experiment.

For a long time the physicians were forbidden the use of the human body for direct anatomical studies; so they used the bodies of the higher animals. The Barbary ape was a classical

subject for early investigation, it being more like man than any other available animal. But comparative study of other animals revealed the same parts in all the backboned animals as in ourselves; and much that we now know concerning our own structures and functions has been learned from the study of the lowly ever-available frog.

The scalpel was for a long time the chief biological instrument, and the field cultivated was comparative anatomy. There is not space to recall here the fascinating story of how the study of comparative anatomy led, with the discovery of fossils, to the science of palæontology; or of how the search for lesser forms and structures led first to the pastime of microscopy, and then to the serious study of modern biology. But from scalpel to microscope and microtome, whatever the method in vogue, whatever the shifts of emphasis, progress has come from two concurrent, essential and complemental practices — *observation and experiment.*

The use of the microscope has become commonplace in our day. It is an indispensable aid in the search for knowledge of things so small that they elude our normal vision. Before its day men spoke of plant and animal kingdoms as remote and distinct entities. The microscope showed how much they have in common. Pansies and pigs look different indeed; but the microscope reveals their common substance, protoplasm, their common units of structure, cells, and many common features in their mode of origin. However, in the beginning, the microscope could not well be applied to the study of creatures so complicated as pigs and pansies. Its use first revealed also a world of little creatures — plants and animals — in which no such vast unlikeness exists. It is in the study of these little creatures that we see most clearly the essentials of organic life, so with these, in the next chapter, we will begin this course.

Man's place in nature is a very old theme. The ancients discussed it; and with every advance in knowledge it has received renewed consideration. In all ages thoughtful minds have sought to know the meaning of life. Out of such knowledge as was available they have wrought imposing systems of speculation as to its origin, its purpose, and its destiny.

In our own day a much broader basis of facts has become available through advances in the science of biology. The microscope has revealed much that was wholly hidden from the ancients. The elements of organic structure and the beginning processes of bodily development could not be seen without the aid of that precious modern instrument. Protoplasm, the physical basis of life, was unknown. The mechanism of heredity was undreamed of.

Thoughtful minds are again dwelling upon the ancient theme — man's place in nature. If they are less hopeful than of old of a complete solution of life's riddle, they are not less eager to know the facts; and more than in any former time, they are trying to make practical applications of the new knowledge.

## APPLIED BIOLOGY

The most important application of the science of biology is *living in this world.* This means the care and control of ourselves in both body and mind. Next in importance is *agriculture,* the art that sustains us, that provides the materials of livelihood. This involves the control of our environment for use. Next in importance comes *medicine,* the healing art; the art that provides correctives for the ills of our bodies, and that, at its best, merely provides aids to natural processes of restoration.

The public interest in biology in our day is shown by the vast array of organizations for the increase and diffusion of knowledge of living things. Our national government makes provision for biological work in most of its executive departments (in 1932) under the following divisions:

| *DEPARTMENT* | *DIVISION* |
|---|---|
| *Agriculture* | Bureau of Plant Industry |
| | Bureau of Animal Industry |
| | Bureau of Entomology |
| | Forest Service |
| *Commerce* | Bureau of Fisheries |
| *Interior* | National Park Service |
| *Labor* | Bureau of Immigration |
| | Children's Bureau |
| *Navy* | Bureau of Medicine and Surgery |
| *Treasury* | Public Health Service |
| | Hygienic Laboratory |
| *War* | Army Medical Museum |

Our government also maintains in Washington the United States National Museum, and the National Zoölogical Park, and sustains in each state the work of the agricultural experiment stations.

The several states likewise maintain their own departments of agriculture, horticulture, forestry, fisheries, health, etc., with varied organization and various names for them. The states maintain

also experiment stations, conservation departments, academies of science and natural history surveys. Cities, also, have their health departments, parks and museums and aquaria. All these exist for the purpose of promoting the application of biological knowledge to human welfare.

## Subdivisions and Relations of Biology

The science of Biology first developed as two independent sciences:

*Botany*, dealing with plants.

*Zoölogy*, dealing with animals.

The recognition of their unity came late. It awaited the revelations of the microscope. However, the study of plants and animals proceeded on parallel lines from the beginning, and resulted in the development of knowledge in four principal interrelated fields:

I. *Taxonomy*, or classification and arrangement of plants and animals; systematic botany and zoölogy.

II. *Morphology* and *development*; the study of form and form changes; comparative anatomy and embryology.

III. *Physiology* and *pathology*; the study of functions of organisms in health and in disease.

IV. *Ecology*, or ethology, or bionomics; the study of organisms in relation to their environment; natural history.

All these are of ancient origin; and to these there has been added in our own generation

V. *Genetics*, or eugenics, the study of the organic relation between the generations of organisms, and of the sources of heredity in the characters of the germ cells; biological inheritance.

In all these fields investigation has proceeded with ever deepening analysis, and subdivisions of each field have developed as separate sciences. We have not space even to name them here. They deal with groups or with processes or with phenomena that can be treated by like methods. Familiar group names indicate the scope of some of them, such as bacteriology, parasitology, embryology, protozoölogy and endocrinology. Purely Greek names characterize the titles of most of the older subdivisions; such as ornithology (birds), herpetology (reptiles), icthyology (fishes), entomology (insects), etc. Anatomy deals with organs, histology with tissues and cytology with cells, and there are

separate sciences for each of the principal classes of tissues and organs, such as osteology (bones), otology (ears), etc.

**Allied subjects** are *chemistry* and *physics*, whose processes underlie and condition all biological activities.

*Psychology* is in one sense a branch of biology, since mind belongs only to living things. Psychology has been defined as "the science of the behavior of living things." In another sense the science of biology is a branch of psychological science, since all its concepts are products of the human mind.

*Education* is a developmental process, at once biological and psychological.

Recognition of the educational value of the study of biology has come about very recently. The introduction of courses in general biology into colleges and universities is remembered by men still living. Although the subject is so new, it is now represented by courses, such as this one, in all reputable modern schools.

## CHAPTER II

# THE SIMPLER ORGANISMS

### I. Algæ

The simplest of green plants are known as algæ. They are very common. When we learn to recognize them we can hardly look into the water anywhere without seeing them. They float in green masses upon the surface; they hang in graceful drapery of verdure on submerged branches; they drip in globules of gelatine from twigs that are lifted out of the water; they rise from the bottom; they lie amid the silt; they trail from the rocks that are swept by the cataract; they cling to wave-beaten piers and boulders; they are free-swimming, and come in our water supply; and they grow and flourish in the bottle of clear water that is long left standing on the window sill. It is not hard to find them in great variety of size and form, and in great beauty and delicacy of organization.

**Closterium** (fig. 1) is a very pretty simple alga that is commonly found in the bottom sediment of fresh water ponds. Although very small, its bright green color and crescentic form make it easily recognizable. If we gently lift up from the pond bottom some sticks that have long lain undisturbed, and shake into a white plate filled with water the silt that covers them, spreading it out in a thin layer, we may usually find Closterium scattered about over the plate. It is visible to the unaided eye, and is easily recognized with a pocket lens. It is easily reared indoors in a cool, well-lighted place in a jar of pond water to which a very little

sugar has been added, and this is the best way to get a large supply. Enough for class study may usually be obtained by mounting the scrapings of silt from submerged leaves, that have lain long in clear, well-lighted water.

A few specimens transferred to a slide and examined with a microscope present at once to the eye some important characteristics of green plants. The crescentic plant body is seen to be encased in a transparent capsule, the cell wall, with a green substance filling the greater part of both ends of the crescent, leaving a transparent, clear band across the middle. In this clear band on closer inspection there is seen a slightly granular substance of such transparency it is at first easily overlooked, and in the center of it is a round body of slightly denser consistency. Although so inconspicuous, it is well to fix attention at once upon these latter structures, for they represent the essentials of living structure. The granular mass is *protoplasm* and the round body within it and forming part of it is the *nucleus*. The green substance filling and obscuring the protoplasm at the sides is *chlorophyl*, and the transparent capsule inclosing the whole is the *cell wall*. The whole plant thus enveloped is a single cell.

FIG. 1. Closterium lunula, *c*, cytoplasm; *n*, nucleus; *w*, cell wall; *r*, chlorophyl-bearing protoplasm; *p*, pyrenoid; *v*, vacuole.

Well down in the angle toward each end of the crescent will be noticed also a round droplet of watery fluid called a *vacuole*, in which, under high magnification may be seen suspended some minute crystals in continuous (Brownian) movement.

Increase of individuals is by cell-division, and this occurs at night, or in the dark. If from a freshly growing Closterium culture a number of individuals be mounted and examined at

midnight, they will be found to differ considerably in size and in appearance at the transparent middle crossband where the nucleus lies. Some of the larger ones will show a broader clear area there, or an indentation of the cell wall at each side, or a constriction extending entirely across the cell, cutting it more or less deeply into two parts, as indicated in figure 2. Closely examined, this process will be seen to be initiated by the division of the nucleus into two parts, one of which passes to each side of the crossband and into the edge of the chlorophyl. The deepening constriction thus divides the mass of protoplasm, and forms two smaller cells out of one large one. Each of the smaller ones, before the separation, is lacking in the crescentic symmetry of the grown plant, the newly formed end being blunter, lacking chlorophyl and vacuole, and having the cell wall thin and not symmetrical with the other end.

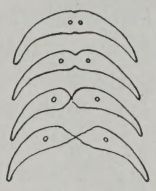


FIG. 2. Division in Closterium; successive stages.

Reflecting on the few readily observable details of this apparently simple process whereby new plants are produced, it is obvious at once that certain of the structures seen are more essential than others. It is the protoplasm that passes on unchanged from mother cell to daughter cells — both the general protoplasm of the cell-body (*cytoplasm*) and the nucleus. About the new end a new cell wall is formed, and in the protoplasm of that end new chlorophyl develops. It is for the sake of the protoplasm that these other parts exist. The normal structure is regained, during the period of growth which ensues. Little is directly observable except the increase in size of the plant.

The two processes of growth and reproduction so simply shown in Closterium, are characteristic of all living organisms, and are their most distinctive phenomena.

Many algæ consist, like Closterium, of cells existing singly, while many others consist of numbers of cells aggregated together to form a more complicated plant body. But whether the plant cell exist alone and apart, or whether it live in contact or in combination with other cells, its parts are usually those seen in the cell of Closterium:

1. Protoplasm { cytoplasm } usually
   " the physical basis of life " { and nucleus } inclosed by,
2. The cell wall, an investing capsule of transparent cellulose which envelops, besides the protoplasm, certain diverse substances of greater or less importance that may collectively be designated as:
3. Inclusions, the more important of which are
   (*a*) the cell sap; a watery fluid which fills all the spaces (vacuoles) unoccupied by the more solid parts and is the medium of exchange of food and waste materials.
   (*b*) chlorophyl, the greenish substance above noted, in the presence of which occur carbon reduction, and the storage of energy of the sun's rays (to be discussed under a subsequent heading), and
   (*c*) secretions, excretions, reserve stores of starch and other food materials, precipitations of mineral crystals (such as oxalate of lime), from the saturated solutions of the cell sap, etc.

**Spirogyra.** — Another alga that is easier to find is Spirogyra. It grows in large masses of slender green threads half floating in the edges of bays and ponds. Many of the green " pond scums " on the surface of clean pools will on examination be found to be composed largely of Spirogyra.

A tuft of it lifted from the water feels slippery, for the threads are encased in a soft transparent gelatinous covering; and the tuft tends to curl at the end like a wisp of hair. If it

be placed in water in a white dish where it can spread out, the length and the unbranched condition of the filaments will be clearly seen.

Examining them with a simple lens, we will be able to distinguish clearly the spiral bands of green that wind about each filament on the inside. These make Spirogyra easy of recognition among other algæ of similar manner of growth (fig. 3).

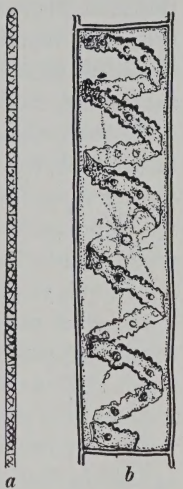



FIG. 3. Spirogyra. *a*, a bit of a filament containing nine cells; *b*, a single cell, more highly magnified; *c*, cytoplasm; *n*, nucleus; *p*, pyrenoids, in the chlorophyl band.

If we then mount a few filaments upon a slide, placing a cover-glass upon a favorable portion, and filling up the space beneath the cover glass with water, we may with advantage apply the compound microscope to the examination of them. Placing the slide thus prepared upon the stage, and examining the delicate filaments with low power of the microscope, we will at once observe that they are not all alike; different species of Spirogyra often grow together, but the filaments of a single species differ: some are of a richer green, with the chlorophyl bands adjusted closer together about the inner walls of the fiber. Let us select for study a filament with the green bands as far apart as possible (so that the internal parts may not be hidden) and examine it as to the arrangement of its parts.

**The cell.** — It will be at once apparent that the plant body is composed of elongate cylindric cells placed together end to end: the filament is a simple linear aggregate of cells. Looking at a single cell, it will be seen to have a rather thick cell wall squarely cut at the ends. The chlorophyl is restricted

to the spiral band, which is not continuous from cell to cell, and which varies considerably in appearance in the cells of different filaments. Focusing upon the upper surface of the cell, the chlorophyl band will be seen most clearly — a beautiful wavy band of green, marked with a narrow median ridge, and studded here and there along the course of this ridge with round bodies containing the pyrenoids. Focusing downward, the band appears below, inclined in the opposite direction, and less clear because of the parts now intervening. Focusing upon the axis of the cell, and looking between the green bands for the more fundamental parts, there will be seen (and, readily, when one begins to see) at the center of each cell a mass of protoplasm containing the nucleus. As compared with the size of the cell, the amount of cytoplasm is small. It consists in: (1) the central mass containing the nucleus, (2) slender strands radiating outward therefrom to various parts of the cell, but chiefly to the pyrenoids, and (3) a thin film next the cell wall. This last fits the cell wall so closely and is so transparent it is hard to see. It may be drawn into view by osmotic pressure, if one only replace the water beneath the cover glass with some denser liquid, such as dilute glycerine, or 5 % salt solution. This outer film will then be seen to shrink away from the cell wall, and if the shrinkage continues, to collapse altogether; but if replaced quickly in pure water, it is soon restored to its original condition; clearly the larger part of the cell is occupied with the watery cell sap, easily withdrawn or replaced.

Thus the main features of structure may be seen in the living cell. But the relations of some of the more delicate parts may be made more clear by the two following experiments. If a drop of iodine solution be placed upon the fibers upon the slide, it will stain the protoplasm yellowish brown, making the peripheral parts of it more apparent.

It will also stain the minute starch granules that lie about the edges of the pyrenoids dark blue or blackish.

If a few fresh green filaments be placed in strong alcohol, the chlorophyl will be dissolved out by the alcohol (more rapidly with the aid of heat) and the protoplasmic matrix in which the chlorophyl is held will be apparent.

**Nitella.** — Protoplasm, the most important thing present in plants, is the thing most difficult to find. In order to get a large enough single mass of it to see without lenses, and to handle, it is necessary to find cells much larger than the ordinary ones, that shall contain it. The common stonewort, Nitella, is an alga with some very large (multinucleate) cells, from which the protoplasmic content is easily removable. It may well be used for a first direct observation on protoplasm. Nitella grows upon submerged rocks in permanent fresh water. It is one of the most highly organized of the algæ. It is attached at its base, bears branches arranged in whorls along its stem, grows apically from terminal buds, and has more of the aspect of familiar plants of higher groups. An examination of its structure (fig. 4) will reveal that its stems and its branches are alike made up of alternating nodes and internodes, the nodes consisting of a ring of short, closely packed cells, the internodes consisting each of a single very large and long cell. The branches arise from the nodes. The internodes are wholly exposed.

FIG. 4. Nitella *a*, the tip of a branch; *b*, a bit of the same somewhat magnified; *n*, node; *i*, *i*, internodes.

It is these very large internodal cells, with their considerable quantity of contained protoplasm, that may with advantage be studied. Since they are wholly exposed to view and have more or less transparent walls, it will be well to

observe first the movements of the living protoplasm as seen under low power of the microscope. A bit of a fresh green spray may be plucked from the top of the stem, placed upon one slide and held flat under another laid upon it for a cover (the space between being filled with water), and thus placed upon the stage for observation. Focusing upon the upper surface of an internodal cell, just beneath the roughnesses of the cell wall will be seen the numerous oval green chlorophyl bodies. At a slightly lower level, by looking intently for a minute, there may be seen the streaming protoplasm, which, though itself transparent, contains minute granules, by the movement of which it may be recognized. These granules will be observed to have a slow, flowing or gliding motion, and they may be traced in a definite path of circulation round about the wall of the cell (as indicated by the small arrows in figure 4). A comparison of different internodal cells will show that the streaming movement varies in rapidity in different ones and is much more clearly seen in some cells than in others.[1]

The protoplasm may be removed from an internodal cell by snipping off one end of it with scissors (after it has been wiped dry) and squeezing the contents out upon a slide. The largest available cells should be selected, for even then the drop of protoplasm obtained is a minute one. Still it is large enough to see and to handle. One may lift it on the point of a needle, and test its viscosity. One may see it with the microscope, wholly uncovered. And if, in looking at it, there is little to be seen, there is enough to reflect upon in the fact that this inert and apparently well-nigh structureless mass is the essential living part of every living thing, much the same in all, and, despite appearances, the builder

[1] In case Nitella be not obtainable, the closely allied Chara (Fig. 48) may be used for the foregoing study; but for observation of the streaming protoplasm, single internodal cells will usually be found only at the tips of the branches.

of all the array of organic life. It is this substance that in the long æons of the past has reclaimed the earth, and clothed it with verdure and peopled it.

**Other common algæ.** — Some hints of the diversity of form in algæ will have been gained from the study of Closterium, Spirogyra and Nitella — the first, unicellular; the second, a linear aggregate, its cells all alike; and the third, a branching, well-integrated body of cells of very different sizes, with terminal buds and apical growth. In figure 5 a few other common forms are shown.

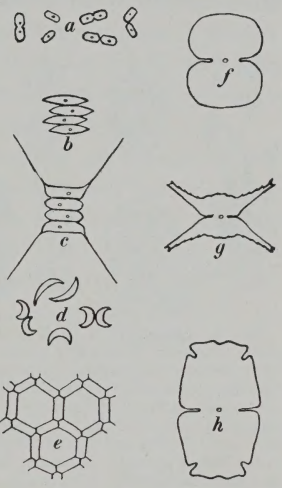



FIG. 5. Miscellaneous green algæ, further illustrating types of cell form and arrangement. *a*, Clathrocystis, actively dividing; *b*, Scenodesmus acutus; *c*, Scenodesmus caudatus; *d*, Selenastrum; *e*, a bit of a net of Hydrodictyon; *f*, Cosmarium; *g*, Staurastrum; *h*, Euastrum.

One observes in studying the algæ an easy transition from unicellular to multicellular forms. First, there are multitudes of single, completely independent cells. Then there are those algæ that consist of practically independent cells that merely hang together. Then there are those that show some differentiation of parts. *Scenodesmus caudatus* (fig. 5) exhibits a beginning of differentiation in the modified form of the two end cells. Then we have a differentiation between base and apex, the one end taking up the duty of securing attachment, the other providing for growth as in Cladophora (fig. 6). Here the filament has become branched.

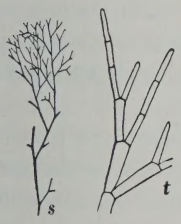



FIG. 6. Cladophora, a stream-inhabiting alga. *s*, a branch; *t*, a tip from the same, to show cell arrangement.

**Chara.** — Finally, we have in Chara, a solid aggregate of greatly differentiated cells. Chara, like Nitella, is made up of a succession of nodes and internodes, but in the former there is one central cell completely surrounded laterally by a layer of slenderer cells (fig. 7). Thus the central cell is completely inclosed and removed from the source of supply of food and air; and it is rendered dependent on its neighbors for its living. And in Chara and in many other algæ there is a high degree of division of labor, certain cells of the plant body being set apart to serve the reproductive process, while others perform the nutritive functions.

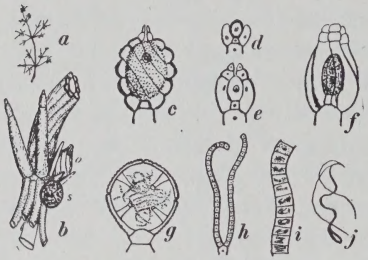



FIG. 7. Chara. *a*, a small branch; *b*, a piece of the stem containing a node and part of two internodes, the lower one having the cortical cells spread apart from the central cell; *o*, ovary; *s*, spermary; *c*, the mature ovary more enlarged, showing the egg cell within; *d*, *e*, and *f*, successive stages in the development of the ovary; *g*, the mature spermary in section; *h*, a pair of spermatic filaments; *i*, a bit of one of the filaments more magnified to show the sperms developing within the cells; *j*, a single sperm set free and very highly magnified.

Our figure shows how the large egg cell is developed, and how the other cells grow up around it and form a container (*archegonium*) for it. The container for the sperm cells (*antheridium*) is, on the outside, like a miniature orange in form and color. Inside it the exceedingly numerous and minute sperm cells develop. They are produced singly within the cells of the long paired and clustered filaments. Thus egg and sperm when mature become very different from the other cells of the body, and different from each other.

## II. Protozoa

The simplest animals are the Protozoans. In a much greater proportion than in the algæ, the cells exist singly. Like the unicellular algæ they consist of few parts, and such of those parts as they have in common are found in every cell — nucleus, cytoplasm, and various inclusions.

**Amœba** (fig. 8) is one of the simplest of animals. We call it an animal because it moves about freely and feeds on other organisms; but at first sight it seems wholly lacking in animal characteristics. It has no legs, nor even muscles, for moving; no mouth for eating; no nerves for feeling; no organs whatever for any purpose. Since the amœba lives an essentially animal life without these parts, a careful study of it may enable us to discover what are the essentials of animal existence.

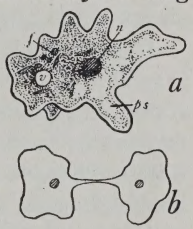



Fig. 8. Amœba. *a*, an active individual; *ps*, pseudopodium; *n*, nucleus; *f*, food; *v*, vacuole; *b*, diagrammatic representation of cell division.

Amœbas are too small to be studied with the unaided eye, and hence, must be mounted upon a slide and looked for with low power of the compound microscope. The larger amœbas live in the sediment on the bottom of ponds and ditches, in the slime on the submerged leaves of aquatic plants, etc. One gets specimens for study by mounting the slime upon a slide and searching until amœbas are found. Since these commonly devour diatoms and desmids, which show their characteristic colors for a time after being engulfed, the process of digestion (as evidenced by the disappearance of the normal plant structures) is in these species more easily observed. In a few moments after their transfer to the slide (the drop being properly covered, and the space beneath the cover glass entirely filled with water), the amœbas should begin to

creep around freely upon the surface of the glass. Although very minute they will be recognized even under low magnification by their form (see fig. 8) and especially by their slowly changing outlines. The details of internal structure in a single animal are not to be observed except with high magnification, and a sufficient cutting down of the light to allow the more transparent parts of the animal to come into view. When found and properly lighted, it will be easy to recognize in the body a granular central mass of protoplasm, a clearer exterior layer, with definite, though slowly changing outline that never shows sharp angles, but only rounded lobes.

The granular internal portion of the body of the animal is spoken of as the *endosarc*. Within it are to be seen: (1) the round and uniformly translucent nucleus, (2) the very clear contractile vacuole, which disappears at intervals, and which usually shows a tinge of pinkish color, and (3) ingested food particles, usually aggregated more or less into round food balls which may be seen moving about in the endosarc. In these food balls the forms of some of the bacteria more recently eaten may usually be recognized. Different individuals will differ much in clearness of these parts, according as they have recently eaten much or little.

The very clear external protoplasmic layer is generally known as *ectosarc*. It shows no definite cell wall, but only an enveloping film; hardly more of this than may be accounted for by surface tension of the body fluids. It has in amœba developed no external skeleton, but remains so clear that through it we may here observe nearly simple naked protoplasm, unobscured, and in action. The movements seen here are quite different from the simple streaming motion in a single current of the internodal cell of Nitella; they are of a higher order of complexity. A portion of the body substance may be pushed out in any direction, but al-

ways in the direction of locomotion, forming the broadly rounded lobes called *pseudopodia:* first a lobe pushes out, and then the granular endosarc streams forward into it. Pushing out forward, and pulling up from the rear with a sort of rolling motion of the body mass is the process of locomotion, and it is dependent upon the contractility of protoplasm.

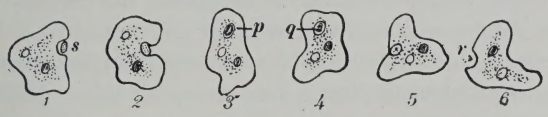



FIG. 9. Amœba. Diagram illustrating in *1*, *2*, *3*, food intake; in *4*, *5*, *6*, removal of indigestible residue; *s*, a food organism; *p*, the same occupying a food vacuole, recently engulfed; *q*, the same partly digested; *r*, residue of same, discharged.

By this same power feeding is accomplished. Two pseudopodia (fig. 9) encircle a suitable bit of food, and press it into the interior of the body, where, engulfed by the protoplasm, it is digested: any indigestible residue is gotten rid of by the reverse process — the protoplasm flows away from it and leaves it behind (fig. 9, *4–6*).

These activities imply volition of some sort or degree, for there appears to be some selection of food and some spontaneity of movement: changes of direction, the taking of a circuitous course in avoidance of an obstruction, etc., indicate this; and since there is only protoplasm present and responsible for the actions, it follows that sensibility, or at least, the capacity for responding to external stimuli, is another property of protoplasm. We tap the slide sharply and the amœbas contract, drawing in their pseudopodia, but soon, after a different interval in different individuals, they resume activity again.

**Paramœcium.** — This is one of the commonest protozoans (fig. 10 *A*). In aquarium jars that are left standing about the

laboratory it is generally present. In order to get a large supply it is only necessary to immerse a handful of hay in a jar of water and leave it so for a week at ordinary room temperature. A surface layer of bacterial jelly will soon form on the water, and in the under part of this layer the paramœcia will live and feed and multiply. They are large protozoans: large enough to be seen with the unaided eye as minute oblong white specks in rapid locomotion.

Specimens for study may be taken up from the edge of the culture, a number at a time, in a dropping tube. They may be seen swimming in the drop of water that hangs on the end of the tube. If this drop be deposited on a slide and left uncovered their swimming may be closely watched with a lens, or better with low magnification of the compound microscope. If they swim too fast to be seen well, their movements may be slowed up by adding a drop of gelatine solution to the drop of water.

The first thing to be noted is that this protozoan has a definite and permanent shape. It is somewhat oblong, slightly widened to rearward, and with rounded ends. An oblique groove (the *oral groove*) extends from the front well down along one side of the body. Thus the landmarks of its body are front and rear ends, oral and aboral sides.

If we follow a paramœcium as it travels about, watching its successive positions carefully, we shall see that it swims in a spiral with the oral groove toward the axis of the spire. Its progress is, therefore, like that of a person ascending a spiral staircase. The obliquity of the strongly margined oral groove is doubtless the chief cause of the rotation of the body around the axis of the spire. The propulsion forward is due to the lashing of the transparent *cilia* with which the whole body is covered.

We may note, also, that whenever paramœcium meets with

an obstruction it stops, backs up a little, turns as on a pivot at the rear end, swinging a little to the aboral side, and starts moving forward again; and if one swing does not clear the object, the process is repeated until a clear headway is gained.

If we apply a cover glass (with some support such as a few threads of cotton under it to keep from crushing the soft animals) and use a higher magnification in examining a specimen that is not moving about, we may see the cilia, that cover its body and that serve both for locomotion and feeding. They are quite transparent, and cutting down the light from the microscope mirror may be necessary to bring them into view. They are of two principal sorts: short locomotor cilia that cover the entire outer surface of the body, and much longer and stouter feeding cilia arranged in a line along the margin of the oral groove. These latter will be seen continually lashing small particles of food into the mouth and down a short rudimentary gullet that leads to the interior. At the bottom of the gullet these food particles may be seen gathered into a rotating ball, that increases for a time in size. Then it breaks into the interior and begins to move slowly along inside. Other food balls, thus formed and ingested, may be seen in various parts of the endosarc.

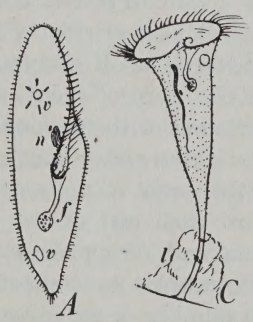



FIG. 10. Two common infusorians. *A*, Paramœcium; *n*, nucleus; *v*, *v*, vacuoles; *f*, food-ball at the bottom of the rudimentary œsophagus; *C*, Stentor; *l*, its lorica.

The entire feeding process may be watched by a very simple experiment. We may mount another drop of water containing paramœcia, first adding to it a little finely pow-

dered carmine, stirring the carmine through the drop. We omit the gelatine this time, but add the cotton and the cover glass, remove excess of water, find a little group of paramœcia confined in some more or less restricted area, among fibers, or at the edge of the cover, and watch them eat the carmine. It is wholly indigestible and may be followed in its entire course through their bodies. Food balls may be seen forming in the neck of the funnel-shaped rudimentary œsophagus that leads inward from the mouth, and those first formed may be seen in their course of circulation round the body, and may in a little while be followed through their entire circuit. By watching long enough we may see one of these balls of carmine discharged through the ectosarc at a point a little to rearward of the oral groove.

It will be seen that Paramœcium eats without selection whatever is small enough to be swept down its œsophagus with the water current, and that it takes in an excess of water along with the food. The mechanism for the removal of the excess water may easily be seen in operation. A pair of rather large vacuoles may be observed in the endosarc, one toward each end of the body, and these may be seen to appear and disappear alternately. Unlike the food balls, these vacuoles are constant in position. Around each vacuole a number of radiating canals will be seen appearing and disappearing at short but rather regular intervals. The excess water accumulating in the body with the food is gathered up in these radiating canals, which then simultaneously contract and discharge their content into the vacuole about which they converge. This then contracts and discharges through the ectosarc to the outside.

Thus in Paramœcium the ectosarc seems to have definite points for reception of food, for discharge of waste food residue, and for emptying the contractile vacuoles. Its

cilia also are permanent organs, unlike pseudopodia in their persistence. These cilia stand upon the surface of a layer of appreciable thickness embedded in which are some additional structures that may be brought to view by another simple experiment.

If we mount another drop of water containing paramœcium, adding thereto a little methyl green or iodine solution, we will kill and stain the animals. There is no need of retainers for they are dead. Adding cover glass and applying high magnification we may see the stinging threads which the killing agent caused to be thrown out from the ectosarc. These will be seen among the cilia along the sides of the body, and will be distinguishable therefrom by their irregularity and unevenness of length.

After staining we may also see the nucleus clearly. It will be green if we used the methyl green stain, or brown if we used iodine. It is in two very unequal portions in Paramœcium, a large irregularly oblong *meganucleus*, and close beside this a small round *micronucleus* (or two of them, depending upon the species of Paramœcium). These seem to have a definite position near the middle of the body.

**Division.** — In a fresh culture containing a large number of individuals, some may be found with constricted bodies in the process of cell division, and if a few of these be isolated and observed, the external phases in the separation of one animal into two may be easily observed. The division is transverse. Numerous smaller, but similar infusorians are likely to be associated with Paramœcium, and often the phenomena of division are more commonly found among these. By staining for the microscope it may be demonstrated that there occurs first a division of both mega- and micronucleus, followed by a subsequent division of the protoplasm.

**Other ciliate protozoa.** — Those protozoans which, like Paramœcium, travel and feed by means of cilia are known as Ciliates. Three other common pond forms that may often be found attached to submerged twigs, leaves, or even to the backs of larger animals will now be mentioned: Stentor, Vorticella and Epistylis.

Stentor (Fig. 10 *C*) is (as its name implies) trumpet shaped when fully extended. It is as if a Paramœcium were drawn out to a stalk at the rear end, and had the fringe of large oval cilia moved to the front end and fashioned into a circular *peristome*. The nucleus is very long. There is one contractile vacuole. The cilia on the sides are small and are arranged in longitudinal lines that correspond more or less closely with lines of contractile substance within the body. There is a small attachment disc at the rear end, and about this end a gelatinous sheath (known as a *lorica*) may be formed. The animal when disturbed contracts down to its base in a globular or oval mass with inrolled peristome. Detached from its support, it swims freely about, rotating as it goes, peristome foremost.

Vorticella is smaller, and consists of an inverted bell-shaped body on a long, slender and highly contractile stalk. Singly it is harder to see with the unaided eye; but individuals commonly occur in groups attached to twigs, forming a whitish fringe that contracts so strongly when touched as to almost disappear. Thus in a group they are easily recognized. The actions of these little creatures are delightful to observe with a lens. They contract with startling suddenness, and expand again more slowly, unfurling a silvery peristome of long rapidly vibrating cilia, and swaying from side to side on their stalks in search of food.

In Vorticella we have a complete differentiation into bell-shaped body and a slender stalk. In the stalk a band of

highly contractile substance extends in an open spiral from end to end, and when this contracts it draws the straight stalk down into a close spiral. At the same time the edges of the peristome are tightly inrolled.

The cilia are restricted to the peristome, the remainder of the body being naked. Detached heads go swimming about with a rotary motion drawn forward by the lashing of these long cilia.

When Vorticella divides the division plane is nearly longitudinal. Just before separation the body appears double; but one half is left in possession of the stalk, and the other becoming detached, moves away and develops a new stalk of its own.

Epistylis is a colonial ciliate. It forms branching colonies because the two cells resulting from a division do not entirely separate, but both remain attached basally to the common stalk, each later prolonging the attachment into a stalk of its own. Successive divisions thus give rise to *colonies*. Such colonies are likely to be found associated with Vorticella, and should be compared therewith. When the colonies are large they are easily distinguished with the unaided eye from clusters of Vorticella by their height, due to their elevation on a common stalk, (fig. 11). This stalk is not contractile,

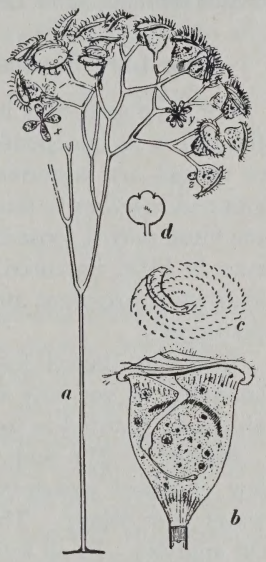



FIG. 11. Epistylis umbellarius. *a*, a portion of a colony; *x* and *y*, successive divisions producing conjugants of reduced size; *z*, conjugation between one of these reduced cells and a cell of normal size. *b*, a single individual in lateral view, showing the elongated esophagus and peristome; *c*, diagram of the top of the peristome, showing its spiral arrangement; *d*, a normal individual, contracted.

lacking the myoneme: myonemes are restricted to the base of the elongated "head" which becomes transversely wrinkled when contracted, and to the peristome which becomes inrolled, as in Vorticella.

## The Life Process in Plant and Animal Cell

We have seen that in many algæ and in most protozoans the cell is an independent organism: all functions of plant or animal are performed by it. Even when such cells are grouped together to form a larger organism, their union is for the most part a loose one, and their physiological independence is little impaired. To the cell, then, we must go to learn what are plant and animal functions, and how they are performed.

How does the cell live and grow? This is a hard question, answered as yet only in part. The answer so far as available is best stated in terms of matter and energy.

**Matter.** — The bodies of living beings are composed of a few chemical elements, such as are common in soil and water everywhere. This is readily determinable by chemical analysis. In all living substance there are nine chemical elements constantly occurring, three others (the three last named below) that are nearly always present, and a number of others occur here and there. The twelve are:

| | | |
|---|---|---|
| Carbon....C | Sulphur.....S | Magnesium. Mg |
| Hydrogen..H | Phosphorus..P | Sodium.....Na |
| Oxygen....O | Potassium...K | Chlorine.... Cl |
| Nitrogen..N | Iron .....Fe | Calcium.... Ca |

The four in the first column, carbon, hydrogen, oxygen and nitrogen constitute over 99 per cent of the living substance, the others being present in very small amounts.

In nature these elements are found everywhere in the

crust of the earth, combined as simple mineral salts, which, being more or less soluble, are found also in the waters of the earth. That these salts will maintain the life of the green plant cell may readily be determined by supplying them to it as food. A commonly used food solution for green plants has the following composition:

| | | |
|---|---|---|
| Distilled water ($H_2O$) | 1,000. | grams |
| Potassium nitrate ($KNO_3$) | 1. | " |
| Sodium chloride ($NaCl$) | 0.5 | " |
| Calcium sulphate ($CaSO_4$) | 0.5 | " |
| Magnesium sulphate ($MgSO_4$) | 0.5 | " |
| Potassium phosphate ($K_2HPO_4$) | 0.5 | " |
| Ferrous sulphate ($Fe_2SO_4$) | a trace | |

Here we have all of the twelve elements listed above except carbon, and this the green plant obtains from the carbon dioxide ($CO_2$) of the air, either direct, if it be a terrestrial plant, or dissolved in the water, if it be aquatic. On such a solution of the simplest mineral compounds green plants thrive. These elements are recombined in the living body into compounds of very much greater variety and complexity, the more important of which fall into two great classes, according as they possess or lack nitrogen in their composition:

I. Carbohydrates and fats: non-nitrogenous compounds, containing carbon, oxygen and hydrogen, but no nitrogen.

II. Proteins: nitrogenous compounds of great complexity.

These substances, formed in, and constituting the bodies of plants, are the primary food of animals.

**Energy.** — The forces that operate upon living bodies are those that operate upon the non-living: gravitation, heat, light, electricity, magnetism, mechanical energy, molecular energy (cohesion, adhesion, attraction of molecules) and chemical energy (chemical affinity, the attraction of atoms).

In the living world, as elsewhere, energy may not be destroyed, but may be endlessly transformed.[1]

The primary source of energy for living beings is the sun's rays. The radiant energy of the sun, acting on the chlorophyl-bearing protoplasm of the green plant cell, effects the cleavage of carbon-dioxide into its two constituent elements, carbon and oxygen. Then ensues the synthesis of the liberated carbon with water to form sugar, which may be transformed into starch, and stored in the tissues. The chemical statement of the reaction (a statement of the shift of the elements only, that tells nothing of the enormous consumption of energy involved) is, in its simplest form, as follows:

| Carbon dioxide | | Water | Fruit sugar[2] | Oxygen |
|---|---|---|---|---|
| $6\ CO_2$ | + | $6\ H_2O$ | $= C_6H_{12}O_6$ | $+ 6\ O_2$ |

This equation expresses graphically the primary synthesis of inorganic materials to form an organic compound.

In order to understand the energy involved it is necessary to take into account the attraction of the atoms. Carbon and oxygen have strong mutual affinity, and combine together in carbon dioxide to produce a very stable compound.

[1] Energy may be either active (*kinetic*) or latent (*potential*). Kinetic mechanical energy is that of a clock spring, moving by the release of tension the works of the clock: it is potential when the spring is wound up, before the pendulum is started swinging. Or it is that of a pile driver hammer falling and delivering a stroke: it was potential when the hammer was lifted and ready to be let fall. Kinetic chemical energy is that of coal burning in an engine, moving the piston: it was potential in the coal. It is that of powder exploding in a gun: it was potential before the cap was struck. Energy was used to wind the clock, to lift the hammer, to combine the unwilling elements of the powder — it disappeared: it was rendered latent or potential.

[2] The simple sugars differ from starch ($C_6H_{10}O_5$) mainly in that they contain relatively more water. The complex sugars differ in being multiples of the simple sugar lacking one molecule of water for each molecule of the simple sugar taken (ordinary cane sugar, $C_{12}H_{22}O_{11}$). Through the series of carbohydrates (sugars, starches, etc.), carbon is combined with hydrogen and oxygen, the two latter retaining the ratio they have in water. The formula of the series, $(C_6H_{10}O_5)n$.

In the above reaction the carbon is separated from the oxygen, and this requires the expenditure of energy — the energy of the sun. In overcoming the strong affinity of carbon and oxygen for each other, this energy disappears, being rendered potential in the separated atoms: it will reappear in like amount whenever these reunite. It is readily measurable in terms of heat. The heat produced by combining twelve grams of carbon with thirty-two grams of oxygen (an ounce and a half of these two elements) is sufficient to raise the temperature of a kilogram (over two pounds) of water from the freezing to the boiling point, and in the separation of like quantities of these elements whether in the electric furnace or in the green leaf, a like amount of energy is rendered potential.

It is easy to demonstrate that starch is formed by chlorophyl-bearing protoplasm only in the presence of sunlight. It is not difficult by proper chemical means to determine the composition of the sugar or starch formed, but it is impossible to follow its formation by direct observation: hence it must be borne in mind, the above equation is a theoretical explanation, based on knowledge of the behavior of the chemical elements, of the nature of the compounds in the food and in the products of the plant, and of the observable phenomena of its nutrition. If so great difficulties attend the explanation of the first step in the synthesis of organic substances, it will be readily appreciated why the succeeding steps are little understood. A purely theoretical explanation of the production of asparagin, one of the simplest of organic nitrogen compounds, of wide distribution in green plants, is that of the following equation:

Glucose + Potassium nitrate = Asparagin + Potassium oxalate + Water + Oxygen

$$C_6H_{12}O_6 + 2KNO_3 = C_4N_8N_2O_3 + K_2C_2O_4 + 2H_2O + 3O$$

The mineral nitrates, sulphates, phosphates, etc., enter into succeeding combinations.

Few proteins have been successfully analyzed; but it is well known that many of them are of exceedingly complex structure. Their molecules are composed of a very large number of atoms, in loose combination. As the size of the molecule increases, the stability decreases, as bricks incline to topple when piled too high. A sample analysis of the molecule of a familiar protein, *hæmoglobin*, from the blood, gives results corresponding to the following formula:

$$C_{600}H_{960}N_{154}Fe_1S_3O_{179}.$$

The reverse process, whereby these complex and unstable compounds are broken up again into simpler ones with the liberation of their energy for the use of the body, is even less understood in its details: it is chiefly known by its results. The end products of metabolism in animals are water, carbon dioxide, urea ($CH_4N_2O$) uric acid ($C_5H_4N_4O_3$) and such other simple nitrogen compounds as ammonia, adenin, xanthin, creatin, etc.; and in plants they are the same except that the nitrogen liberated by proteid dissimilation is recombined and does not appear as waste.

While the analysis of the processes involved in the metabolism of the living substance is difficult, and details are somewhat uncertain and only the beginning and the end steps have hitherto been traced, there is no doubt whatever about a number of the main facts:

1. That the organic life of the world is supported on water, carbon dioxide and simple mineral salts, gathered and assimilated by the green plant cell.

2. That these mineral substances are of simple composition, are composed of but few elements united strongly, and that they are very stable, and devoid of potential energy.

3. That the non-nitrogenous substances first combined under the power of the sun's rays, are compounds of a higher order of complexity of less stability and of much more potential energy.

4. That the nitrogenous substances (proteins) are of great diversity and of exceeding great complexity of structure, very unstable, and of very high potential energy.

5. That protoplasm is a complex substance (not a single chemical compound), probably a mixture or combination of various proteins, water, etc., so unstable it is impossible of analysis for, to analyze it kills it, and death initiates changes altering its composition.

6. That the primary source of energy is the sun, drawn upon by the green plants first; the supply for other organisms is the potential chemical energy of manufactured carbohydrates, proteins, and of free oxygen.

**Protoplasm,** the physical basis of life, the living part of every living thing, and essentially the same in its general properties and functions in all, possesses in green plants the capacity for developing chlorophyl, through the agency of which the energy of the sun can be utilized in effecting such analysis of simple mineral compounds and such synthesis of more complex organic compounds as result in the storing up of a large amount of energy. Then the living substance acts as a chemical engine, using the energy of these same organic compounds, and in that use, reducing them again to simpler ones. Here as elsewhere, neither matter nor energy is created or destroyed, but both are endlessly transformed. The living body is constantly changing. It is only the constancy of the stream of income and outgo that allows it to present a semblance of an abiding presence. It is like the chemical engine in that it uses fuel — the food — whose transformation into gases and ash liberates energy for its

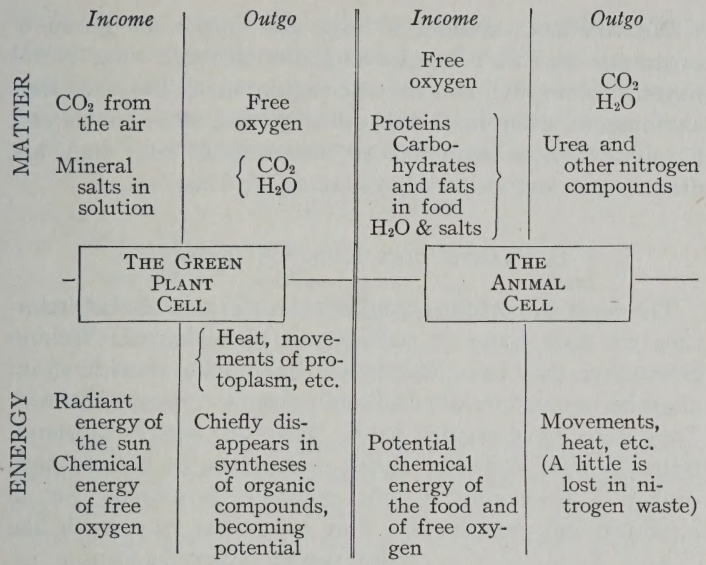
work. It is unlike the engine in that, far from being a mere contrivance of chambers in which transformations and reactions may occur, it is itself changed constantly, formed and reformed, regularly gathered from and returned to the stream.

The dissimilation process (*katabolism*), whereby the complex organic compounds are broken up into simpler ones, with the liberation of their energy for use, has not hitherto been traced step by step in detail: indeed, it is even less understood than the assimilative. Its results are well enough known: the end products are simple compounds, $CO_2$, $H_2O$, and nitrogen compounds not wholly reduced to the grade of composition they had when first taken up from the water (and therefore, a little energy that they still retain is lost to the body). Their energy has reappeared in various forms, mechanical movement, bodily heat, luminescence, etc.

From the chemical side it therefore appears that assimilation (*anabolism*) is the process of separating chemical affinities and of storing up chemical energy in complex compounds, and that dissimilation (*katabolism*) is the process of reuniting affinities in stable compounds with the liberation of energy for use.

Plant and animal differ in the nature of their collective intake and output of matter and energy, and the main features of that difference are expressed graphically in the accompanying diagram.

In this table the facts are of necessity stated broadly. For example oxygen is given off by the green plant only in the light; and when the reduction of carbon dioxide (*photosynthesis*) is in progress. At all times some oxygen is being used by the active plant cell. In fundamentals of the life process (*metabolism*) plant cell and animal cell are exactly alike.




## III. Some Intermediate and Undifferentiated Forms

The typical algæ and protozoa studied thus far, conform to our general notion of *plant* and *animal*, derived from contact with the higher, familiar forms of life. The green color of the plant and the free movement of the animal seem at first to mark out naturally two distinct groups; among the higher forms there is no difficulty about distinguishing between plant and animal. It is easy to tell a dove from a daffodil; it is not hard to tell a green alga from a free swimming gray protozoan; but there are among the lower organisms some that do not clearly show even the broad distinctions of the preceding diagram, and some that so combine the characters of the two groups that one may not say with assurance whether they are plants or animals.

We will first consider a large and important group of organisms that we recognize as plants although they do not contain chlorophyl, and they do require much the same food as animals; after that, two other groups, slime molds and flagellates, with characters so intermediate that they are discussed in textbooks of both botany and zoölogy.

## I. Plants that Lack Chlorophyl

The most important common characteristic of the organisms we now come to consider, is physiological: lacking chlorophyl, they have abandoned the primary plant function of gathering food materials directly from the inorganic world. They must have organic food. They can derive no energy from the sun, and they thrive often quite as well without sunlight. They use the same foodstuffs as animals; yet in structure and growth-habit they are plants very much like green species of parallel form.

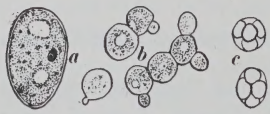



Fig. 12. Yeast. *a*, a single cell showing nucleus (dark colored), two vacuoles, and numerous fat droplets; *b*, clusters of growing and budding yeast cells (*torulæ*), in various stages of development; *c*, spores, formed on drying, four within each cell wall.

**Yeasts.** — These are unicellular chlorophylless plants of the group of fungi. Isolated cells have, save for their gray color, much the appearance of single cells of protococcoid algæ. They have cellulose in their walls; their protoplasm is somewhat more granular, contains minute fat droplets and is without a trace of chlorophyl.

The process of cell multiplication is peculiar. It is called budding (or *gemmation*). Minute processes are pushed out from the side of the cell, and these grow up gradually to full stature, adhering for a time to the parent cell. Often the new cell starts buds of its own before it is fully grown itself. Thus

while growing quietly the cells come to be assembled in little clusters or families of cells (*torulæ*), as shown in fig. 12.

A food solution for yeast that bears the name of the great biologist, whose fame rests in part on discoveries he made of the part yeasts play in fermentation, is the following:

*Pasteur's Solution*

| | | |
|---|---|---|
| Water $H_2O$ | 83.76 | % |
| Cane Sugar $C_{12}H_{22}O_{11}$ | 15.00 | " |
| Ammonium tartrate $(NH_4)_2C_4H_4O_6$ | 1.00 | " |
| Potassium phosphate $K_3PO_4$ | 0.20 | " |
| Calcium phosphate $Ca_3(PO_4)_2$ | 0.02 | " |
| Magnesium sulphate $MgSO_4$ | 0.02 | " |

If this formula be studied it will be discerned that the chemical compounds of the food of yeast are intermediate in kind between those of animals and those of green plants. Some of the same mineral salts are used by both green and colorless plants. The nitrogen is obtained from a somewhat more complex compound in the latter. Only the sugar is properly an animal food. Proteins such as animals require are wholly lacking. It will be noted that there is carbon in the formula aside from the sugar: the yeast will live, indeed, in this solution if the sugar be omitted but its growth will then be very slow. It will be noted also that the sugar is present in very great excess of the need of the yeast for carbon. The yeast plant contains a sugar ferment. It utilizes only about one per cent of the sugar, and decomposes the remainder into carbon dioxide and alcohol. The reaction of the fermentative decomposition may be expressed as follows:

| Sugar | | Alcohol | | Carbon dioxide |
|---|---|---|---|---|
| $C_6H_{12}O_6$ | = | $2C_2H_6O$ | + | $2CO_2$ |

It is the production of these two by-products that makes yeast commercially important. Yeast produces the same reaction in the sugars of cider and wines, and in the metamorphosed starches of the cereal grains, that are chiefly used in commerce in the production of alcohol. The carbon dioxide is also utilized in the making of bread. Yeast is mixed with the dough, and, fermenting in it, evolves the carbon dioxide gas, which "raises" it, making it porous, and improving its digestibility and flavor.

If a little fresh yeast be sown in a bottle of Pasteur's solution (or even in a 15% sugar solution made with tap water, which will be likely to contain enough of the mineral salts for considerable growth), and kept in a moderately warm place, within twenty-four hours abundant growth will be evidenced by the increasing turbidity of the liquid, and by the taste of the alcohol in it and by the odor of the escaping carbon dioxide [1] arising from it. It may be demonstrated by examination of a drop of the fluid with the microscope.

**Molds and other fungi.** — These are chlorophylless plants of different organization. They parallel the filamentous algæ in their structure. Penicillium (figure 13) consists of branching filaments recalling in their form those of Cladophora. Molds live for the most part on a more or less solid substratum of organic matter and reproduce vegetatively by means of spores that are distributed through the air. Therefore, they have differentiated into two parts: the *mycelium*, the part immersed in the substratum, and concerned with

[1] A simple chemical test of the presence of $CO_2$ in the escaping gas may be made by thrusting a glass rod with a drop of lime water suspended on it into the mouth of the culture bottle. The calcium oxide (CaO) of which lime water is a solution, readily unites with free carbon dioxide to form a white precipitate of calcium carbonate $CaCO_3$ ($CaO + CO_2 = CaCO_3$) which may be seen to form in the drop.

gathering food, a tangle of slender root-like filaments; and slender aerial *sporophores* that rise from the mycelium at time of fruiting and bear the spores.

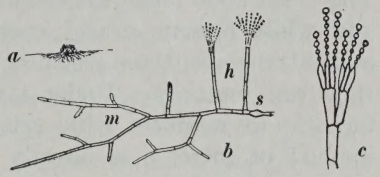



FIG. 13. Penicillium. *a*, a little tuft of the mould, as it appears, growing on the surface of a nutrient medium; *b*, a bit of the same, magnified; *s*, the original spore; *m*, mycelial filaments; *h*, sporophores, with spore clusters; *c*, one of the spore clusters.

Many molds feed upon the bodies of plants and animals, living and dead, and upon materials extracted therefrom, obtaining both their carbon and their nitrogen from organic compounds. Many others (known as rusts, blights, mildews, etc.) are destructive pests of green plants. But most of them are saprophytes, and assist in the circulation of food materials in the earth by hastening the decomposition of the bodies of dead plants.

FIG. 14. A disc fungus (Peziza?). *j*, the aerial part of the fungus, with a quarter section cut out to show *h*, the hymeneum. *k*, a bit of the hymeneum showing, *a*, ascus, containing spores; *n*, sterile paraphyses, and *m*, sub-hymenial tissue. *l*, a bit of the involucre surrounding the hymenium.

The fruiting stages of the higher fungi are aggregates or integrates of filaments, that rise collectively from mycelia, and fashion together parts of various forms: spheres in the puffballs, with the spores borne inside: low cup-shaped receptacles in some of the disc fungi, or Ascomycetes (fig. 14), with the spores contained in cylindric spore sacs (*asci*) in a fruiting layer (*hymenium*) in the bottom of the cup: umbrella-shaped caps in mushrooms and toadstools, with the spores borne on the vertical surfaces of radiating plates underneath the cap.

**Bacteria.** — These are the smallest of the chlorophylless plants — indeed, they are the smallest of living organisms. They feed upon much the same materials as do other fungi, and while present nearly everywhere, they are sure to abound wherever there are moist organic substances in which they can multiply. Under favorable conditions bacteria increase in numbers with extraordinary rapidity. Their method of increase is already familiar — growth in size, followed by cell division. A division may recur every hour, and at this rate something like 17,000,000 individuals might appear as the offspring of a single one in the course of twenty-four hours. Obviously, such a rate could not long be maintained for want of food. Their reproductive capacity, together with the readiness with which they may be distributed, give them an important place in the economy of nature. Through aid of decomposition they play a large rôle in restoring spent organic materials to circulation.

Certain bacteria at times develop spores. Usually but a single spore is produced in each cell, the protoplasm of which develops a resistant spore coat within the old cell wall (fig. 15). The spores are not injured by drying, and may be heated even above the temperature of boiling water without being killed. They are readily distributed everywhere by currents of air.

Bacteria serve their disintegrating function quite without regard to human interests, — spoiling foods, or rotting the compost heap to enrich the soil; souring milk, or ripening cheese; disintegrating living tissues in disease, or aiding the processes of digestion, etc. Although the study of bacteria has been possible only during the brief period that has elapsed since the invention of good microscopes, their effects have always been known, and many empirical methods have been used for combating their growth. They do not thrive in

acid solutions, hence acids have long been used as a means of preserving foods, as in the process of pickling meats, fruits, etc. They do not thrive in heavy solutions of sugar, and hence jellies and preserves are composed of large proportions of sugar. They require 25 per cent or more of water in their food substances for normal growth, and hence the reduction of the proportion of water present by the drying of meats and fruits has long been practiced: also, the use of salt to make such water as is present unavailable. Substances whose presence is inimical to their growth, we now know as antiseptics. These are the mainstay of modern surgery (bichloride of mercury, etc.), but of old, wounds were forefended against bacteria by the pouring in of oils (such as turpentine) and of alcoholic solutions (strong wines).

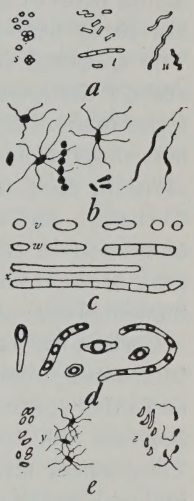



FIG. 15. Bacteria *a*, form types; *s*, coccus, *l*, bacillus; *u*, spirillum types. *b*, these forms stained, some showing flagella, others, none. *c*, types of division; *v*, ordinary cell division; *w* and *x*, simultaneous division of longer filaments into a number of cells. *d*, spore formation in different forms. *e*, two species of bacteria of the bacillus type, showing differences of appearance, both stained and unstained; *y*, the typhoid bacillus; *z*, the bacillus of Asiatic cholera.

All these methods, applied without knowledge of the causes of the evils they sought to cure, have been vastly improved with the development of bacteriology. New processes of treatment by antiseptics, by sterilization, etc., have been developed and old ones have been improved. We now have transparent culture media, containing suitable food. We sterilize the culture media, even as housewives have always sterilized fruit for canning, sealing while hot. By this method we clear the field. Then we sow in the culture media the sort of bacteria we wish to study, and observe their habits and manner of growth.

In order to see bacteria, rather high powers of the compound microscope are required, and even with the best instruments little of internal structure is visible in them. There are three form-types commonly found among them: (*a*) The spherical *coccus* type, (*b*) the rod like *bacillus* type, and (*c*) the *spirillum* type (fig 15). Under each of these form-types many different species occur, which may differ in size and proportions, in manner of grouping, in mode of cell division, etc.; or, different species may appear quite alike to the eye, and may be distinguishable only by their manner of growth in culture media. By proper staining methods some of them show locomotor flagella, that are quite invisible unstained (fig. 58 *b* and *e*).

Certain soil bacteria, of very great importance to agriculture, cause minute tubercles to grow upon the roots of clover and other leguminous plants. These are important because they are able to derive their nitrogen directly from the air. They supply nitrogen to the clover, and thus repay the debt imposed by the parasitic life. They enable the host plants to grow upon soils that are poor in nitrogen, and by their decomposition they leave such soils richer than they found them.

Within the tubercles these bacteria grow larger than other forms, the cells becoming irregularly rod-shaped, x-shaped, y-shaped, etc. Hence they are easily recognizable with the microscope. Upon examination of the large tubercle we ordinarily find them filling the interior. Upon the dissolution of their bodies, their nitrogen content is added to the soil, either directly, during the growing season, or indirectly through the intermediary agency of the clover.

### The Slime Molds

These are organisms of mixed character. In certain phases of their existence they exhibit animal functions; in

other phases, only plant functions. In textbooks of zoölogy they are called Mycetozoa; in most texts of botany, Myxomycetes.

Slime molds live during the greater part of their life as spreading masses of naked protoplasm (*plasmodia*), which slowly creep about through the tissues of rotten logs, stumps, leaves, etc., like giant amœbas. They are soft and slimy to the touch, and are of a consistency about like that of the white of an egg. Their prevailing tints are yellow, brown, ecru or purplish, or almost any color except green. They are usually small, but with plenty of food and moisture, a single plasmodium often grows to be a foot across. They shun the light and are always to be looked for in sequestered places. During nearly the whole of the growing season, from early summer until late autumn, they may be found in deep mossy woods, and in shaded places by permanent springs. On damp, muggy days following warm summer showers the plasmodia may be found, outspread upon the surfaces from which they draw their nourishment. They are saprophytes. They feed on the dissolved organic substances of decaying stems and leaves. They are always found associated with fungi of similar habits, but unlike the fungi they may also take solid food, engulfing it as does an amœba by surrounding it with outflowing protoplasm.

Each plasmodium is a single multinucleate mass of protoplasm, without separating cell walls. The nuclei divide and become very numerous, but there is no distinction of cells. A plasmodium may become divided by the flowing apart of its mass in divergent directions, or two plasmodia may meet and wholly coalesce. They possess little individuality.

Dry weather checks the growth of the plasmodia and often initiates the reproductive phase of the life of the slime

molds, in which they resemble plants. The plasmodia then abandon the darkness and creep out upon the exposed surfaces of the log or stump, or a little way up the stems of nearby plants. They develop cell walls about all their nuclei and these walls are composed of a characteristically vegetable substance, cellulose. Their most elevated portions develop sporangia of various and often beautiful forms (fig. 16). These contain multitudes of spores. This maturing process takes place very quickly — a few days or even hours may be sufficient; it is to be sought on the bright and sunshiny days that follow summer showers.

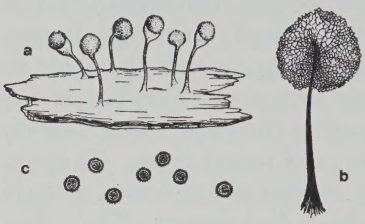



FIG. 16. A slime mold in spore bearing stage. *a*, sporangia springing from rotten wood; *b*, a single sporangium; *c*, spores highly magnified.

The spores are scattered with the bursting of the sporangia at maturity. In some of the commoner slime molds they are assisted in making their exit by the movements of certain spirally twisted threads (*capillitial threads:* collectively the *capillitium*) which occur in the sporangia with them. These threads, formed from residual shreds of the plasmodium, are very hydroscopic, and when they dry out, twist and turn vigorously, scattering the spores. When favoring wind or water bears a spore to a favorable place for germination, it bursts its cell wall and there creeps out therefrom a minute, naked amœboid cell, which moves about for a time by means of pseudopodia. Then it develops a long lash at one end of the body (fig. 17) with the aid of which it swims for a short time. Then it settles down, in company with others of like kind, and with the others fuses into a plasmodium of minute size.

Thus we see that from the time of germination of the spore until the plasmodium is mature, the slime mold exhibits the free locomotion and the feeding habits of the animal,

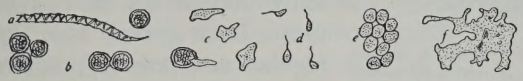


FIG. 17. Reproduction in slime molds. *a*, elater; *b*, spores; *c*, one germinating spore and three amœboid cells escaped from other spores; *d*, the same cells a little later when free swimming; *e*, convergence of these cells to form a plasmodium; *f*, a small plasmodium.

while thereafter it develops cellulose cell walls and produces spores like a plant. Nature has not always established hard and fast boundaries, even between her major groups of organism.

## THE FLAGELLATES

Unlike the slime-molds, the flagellates are minute organisms having considerable definiteness of body structures, yet some of them have not clearly and uniformly differentiated plant and animal characteristics. Hence these, also, or at least some of them, are treated in books on both botany and zoology; in the former being ranked with the protococcoid algæ, in the latter with the mastigophorous protozoa.

**Euglena** is a common flagellate that will serve for introduction to the group. It abounds in sluggish waters, and if some bottom silt from a duck pond be placed in a large glass jar and allowed to stand awhile, Euglena will usually be found swimming in numbers at the surface on the side next the light. If abundant it will be very evident by its bright green color. It may form a green film on the surface visible to the unaided eye.

If a drop from this film be mounted for the microscope and examined one sees as soon as he finds the organisms that they exhibit the bright green chlorophyl color of the

algæ along with the active swimming movements of very lively protozoans. The swimming is rapid, and at first it may be difficult to keep a single individual in the field of observation. It is jerky, too; not the regular and orderly progression of a ciliate, but quick movements from side to side, due to the lashing of the long flagellum at the anterior end of the body (see fig. 18).

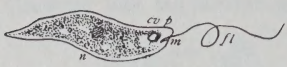



FIG. 18. Euglena. *n*, nucleus; *m*, mouth; *cv*, contractile vacuole with pigment fleck, *p*, beside it; *fl*, flagellum.

In an individual that has settled to creeping about on the slide one may observe the form of the body — oval, blunt in front and pointed at the rear, showing a transparent ectosarc, and an endosarc filled more or less completely with green chlorophyl, and containing near the front end a pigment fleck of more or less orange color. The flagellum may be seen to be as long as, or longer than the body. It may be broken off, however, and if present it is so transparent it can only be seen in very favorable light, or sometimes, only after staining. Beside its base is a cleft — a rudimentary mouth — a receptacle for solid food — another animal character. In the midst, more or less hidden by the chlorophyl and by engulfed foods, is the nucleus. Reproduction is by fission, which, also, may be observed in favorable specimens.

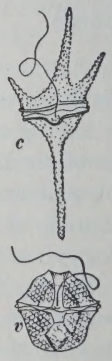



FIG. 19. Two shell-bearing flagellates; *c*, Ceratium, and *v*, Peridinium.

Ceratium is a free-swimming flagellate which secretes a spinous shell that is probably a protection against the attack of some of the predaceous animals of its environment (fig. 19). Peridinium is encased in a brownish sculptured shell.

Dinobryon is a colonial flagellate which develops an urn-shaped membranous shell open at the anterior end: two flagella of unequal length project from the opening; the chlorophyl is distributed (fig. 20) in two elongate tracts within the body, and is somewhat obscured, as in many other flagellates, by a yellowish pigment.

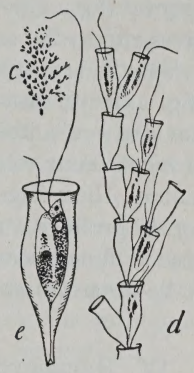



FIG. 20. A colonial flagellate, Dinobryon. *c*, a colony; *d*, a portion of the same more enlarged; *e*, single individual.

Upon division, one of the resulting daughter cells slips out to the rim of the urn-shaped shell, and secretes for itself a new shell of like form, attached at the base within the margin of the old one. Repeated divisions thus give rise to branched colonies. These go swimming about in the water in a most absurd fashion — a contradiction to all the mechanics of submarine navigation — the open end forward, as it must needs be, owing to the position of mouth and flagella.

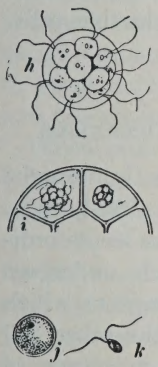



FIG. 21. A colonial flagellate Pandorina. *h*, a normal spherical colony; *i*, daughter colonies developing within the cell walls of the mother colony; *j*, zygote resulting from the fusion of the gametes; *k*, gamete; gametes are often of unequal size.

Pandorina (fig. 21) is a small spherical colony of biflagellate cells. Usually there are sixteen (sometimes only eight, more rarely, thirty-two) of the cells, closely held together in a gelatinous envelope. New colonies are formed in two ways:

(1) repeated divisions within the old cell wall give rise to new colonies, which escape as colonies and not as single cells (fig. 21 *i*).

(2) each cell of a colony may divide four or five times

giving rise to sixteen or to thirty-two cells (sex cells, or *gametes*) which escape singly and fuse in pairs, forming zygotes (fig. 21 *j*). Each zygote, later, by successive divisions gives rise to the normal colony.

Volvox is a spherical colony of somewhat similar cells (fig. 24). It grows to large size, being easily visible to the unaided eye, and it may contain hundreds or even thousands of constituent cells, all embedded in the common gelatinous matrix, their flagella radially protruded and lashing in unison to produce a rolling motion. Volvox presents a remarkable differentiation into vegetative and reproductive cells, to be discussed under a subsequent heading.

## IV. Reproduction Among the Simpler Organisms

**1. Cell division.** — Increase of individuals is brought about among the simpler organisms, as we have already seen, by simple cell division, or *fission*. This process seems ordinarily to be initiated by the nucleus (which undergoes changes to be described in a subsequent chapter) which separates itself into two parts, about which the other cell constituents become arranged. The living substance of the mother cell thus lives on in the two daughter cells.

Cell division is an automatic, internal, spontaneous process. It cannot be effected artificially; it cannot be compelled or prevented. If a cell be cut in two, the part of it containing the nucleus and a part of the cytoplasm may live, but the cytoplasm deprived of the nucleus dies, and a wholly isolated nucleus dies also. The cell is the unit of organic structure and function, and in it nucleus and cytoplasm bear relations of mutual dependence. They work together in both nutritive and reproductive processes.

Cell division results from growth, the increase of size dis-

turbing the nutritive relations between the living substance and its food supply: for volume tends to increase faster than surface; the former (if the cell be spherical) as the cube, the latter as the square of the diameter. Therefore, the mass of protoplasm tends to increase more rapidly than the surface through which it derives its nourishment and expels its waste. This is a sufficient reason why cells are small, and why, when a standard maximum size is reached, the process of division sets in to keep them so.

For every kind of cell there is a normal size, which being attained, nucleus and cytoplasm act conjointly to bring about a separation of the cell body into two equal parts, and to perpetuate in each of the descendant cells the substance and the characters inherited from past cell generations.

When cells after division remain in contact they tend to form individuals of a higher order. These may be merely colonies of loosely associated and physiologically independent cells — mere aggregates — or, if the cells become intimately associated in relations of mutual dependence, then each aggregate becomes a unit organism. In organisms of this compound sort new individuals may be formed by external agencies. The filament of Spirogyra, for instance, may be broken into a number of parts, and each part, provided it contain an uninjured cell, may become a new filament. New individuals of such branching types as Cladophora or Dinobyron are formed when the older parts connecting branches together meet with accident or death and the connection is dissolved. These are negative processes, that do not account for the production of anything new; it should be clearly recognized that cell division is the universal mode of increase among organisms.

**2. Sexual reproduction.** — In a few minor groups of the smaller organisms, cell division goes on uninterruptedly, and

is the only known phenomenon of reproduction; but in all the larger and higher forms of life (and in so many of the simpler ones also that it is well nigh universal) another phenomenon known as conjugation or sexual reproduction enters in periodically, alternating with long periods of cell division. This process consists in the fusion of two cells, and so, is the reverse of cell multiplication. Like cell division, it is an automatic spontaneous act of the cells themselves, that cannot be artificially performed. It seems to follow a decline in vegetative vigor. This is indicated by the loose amœboid form taken on by certain shapely flagellates (fig. 22) just previous to conjugation. It is followed by restoration of the normal form, and by renewed activity in cell division, therefore, it seems to be a sort of rejuvenating process.

FIG. 22. Cercomonas (in part after Dallinger). *a*, division; *b*, a normal individual; *c*, an individual approaching the time for conjugation; *d*, the beginning of conjugation; *e*, end of conjugation and fusion of nuclei.

It introduces into cell lineage new influences from without, by commingling the substance of two cells that are of diverse ancestry and that have lived apart under different influences.

This fusion may occur among the simpler organisms in a great variety of ways. It may be temporary and partial as in Paramœcium. Two individuals come together and partially fuse at the anterior end. Their meganuclei degenerate; their micronuclei divide; a part of each micronucleus passes over into the other Paramœcium to fuse with a corresponding

part of the micronucleus of that animal, the two together forming the new micronucleus. The two paramœcia, after this exchange of substance, separate, and enter upon another period of increase by fission.

More often the fusion of cells is total and permanent. It may be between cells that are of normal size and equal activity (fig. 23), as in Closterium. Spirogyra shows the slight difference that one of its conjugating cells is more active, its protoplasm passing over bodily into the other one. In Epistylis (fig. 11) there is greater difference in size and the active cell possesses locomotor cilia and is free-swimming.

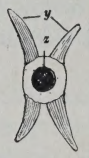



FIG. 23. Diagram illustrating conjugation between two cells of Closterium; *y*, the empty and discarded cell walls; *z*, the zygospore, or zygote, resulting from conjugation.

It usually occurs, even among the simpler organisms, between two specialized reproductive cells (*gametes*) of complemental character:

| | |
|---|---|
| SPERM (or *spermatozoan*) | small — active — with little cytoplasm and no inclusions. |
| EGG (or *ovum*) | large — receptive — cytoplasm charged with food materials. |

This alone is *sexual* reproduction, since in absence of this differentiation there is no sex. Sex cells are well illustrated in Volvox (fig. 24). The many generations of cells produced by fission remain in contact and constitute the spherical colony. A few scattered cells in the colony cease their vegetative activity and become differentiated in two ways. Some of them repeatedly divide until very small, develop swimming flagella, and are liberated as free-swimming sperms. The others increase in size and food content by storing up in their cytoplasm food materials derived from neighboring cells, and become eggs. At maturity the sperms break out

and swim abroad. The egg remains where produced, and develops only if some wandering sperm find it and fuse with it. After such fusion (*fertilization*), ordinary cell division begins again; and the little cluster of cells soon formed is set free as a new minute volvox colony.

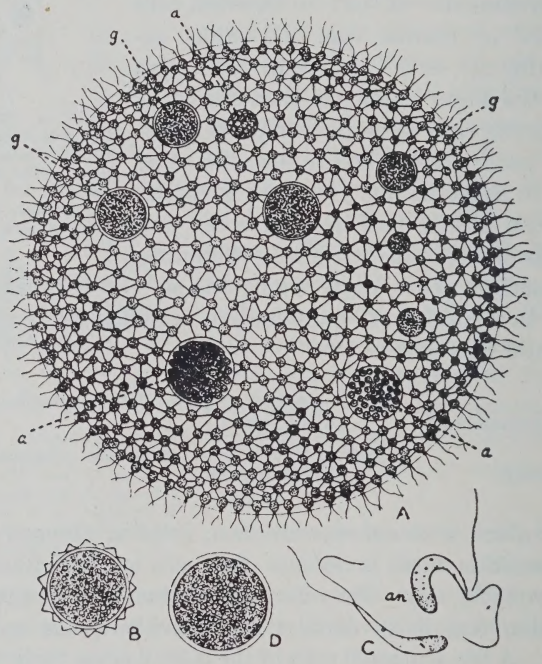



FIG. 24. Volvox (from West, after Klein). The individual cells are united by radiating strands of protoplasm. *A*, a mature colony; *a*, spermaries; *g*, ovaries. *B*, zygote resulting from the fusion of the gametes. *C*, two sperms. *D*, egg.

The stoneworts, Chara (fig. 7) and Nitella, show the same phenomena, with eggs and sperms developed within much more highly specialized chambers (ovary and spermary

respectively). In the other forms we have been considering any cell might enter into conjugation. But here, the greater part of the cells of the body (*bodyplasm*) eat and grow and die without descendants, and only the few that are relieved of nutritive functions and set apart for reproduction, live on in succeeding generations.

In this chapter we have sought out a few of the simpler living things in order to see what life is like when reduced to its lowest terms. Some have been clearly plants; some, clearly animals; and some, not clearly either. All are composed of protoplasm. In all, this wonderful substance is organized into cells. In all, increase is by cell division.

All are simple as compared with the forms to be studied in succeeding chapters. Yet protoplasm is not simple. The cell mechanism we can only describe without explaining the functional relations of its parts. Increase by cell division, and increase following sex-cell fusion, and the relation between the two, are full of baffling problems. Life itself is never simple.

These forms have been mainly aquatic. Life probably began in the water. Protoplasm is a liquid substance; and metabolism is compatible only with a liquid state. These organisms suggest what the beginning of life on the earth may have been like. They at least have shown a high degree of cell differentiation, and a beginning of cell integration to form a multicellular body, a start toward tissues and organs, and a beginning of sex.

## CHAPTER III

# THE HIGHER PLANTS

There are but two main groups of organisms — plants and animals. If these are not always sharply distinguished among the lower organisms, they are distinct enough among the higher ones. Our next study is, therefore, of two series of forms, illustrated by a very few types that will serve to show the more important features of their structure and development.

The briefest admissible classification of plants is the familiar one that assembles algæ and fungi into one group, and makes of the remaining plants three groups that are somewhat more homogeneous and consistent, as follows:

Thallophytes; algæ and fungi.

Bryophytes; liverworts and mosses.

Pteridophytes; ferns, etc.

Spermatophytes; the seed plants.

We have already studied a few representative Thallophytes; we shall now briefly examine a few representatives of each of the three other groups.

## I. BRYOPHYTES

### Liverworts and Mosses

This is a group of comparatively small plants, of very great diversity in appearance. Those that live in the drier situations, and that are more familiar to us, are mainly mosses; but liverworts are common also in their proper haunts; in the moist shaded places of deep woods; on wet rocks by streams.

**Conocephalus** (fig. 25) is a good liverwort with which to begin our study of the group. The plant body is a broad flat *thallus*, which spreads over and attaches itself closely to the soil. It is of bright green color, and has a peculiar, somewhat musty odor. It grows apically, in a zig-zag course, dichotomously branching alternately to right and to left, the branches and parent stem being of equal breadth.

If we tear up a little strip of the thallus from the soil, we observe at once a considerable number of parts not seen among the algæ. First, there is a multitude of slender

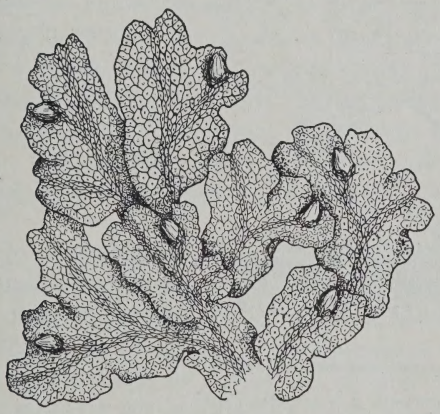


FIG. 25. A fruiting spray of Conocephalus.

white rhizoids, holding the plant body fast to the soil. These are feeding organs. A number of algæ (for example, Chara, and Nitella) have similar organs for attachment, but they are much less developed and seem to have no feeding function. In the liverwort, as in most of the higher plants, rhizoids are the chief means of taking up dissolved mineral substances out of the soil. The torn end of the thallus will

show, also, that the plant body is covered with a dry surface layer of cells that is protective to the moist internal tissues. This surface layer is *epidermis*. Examined with a lens, it will be seen to be marked out in minute polygonal areas all over the upper surface of the thallus and on close inspection a minute pore will be seen in the middle of each of these areas.

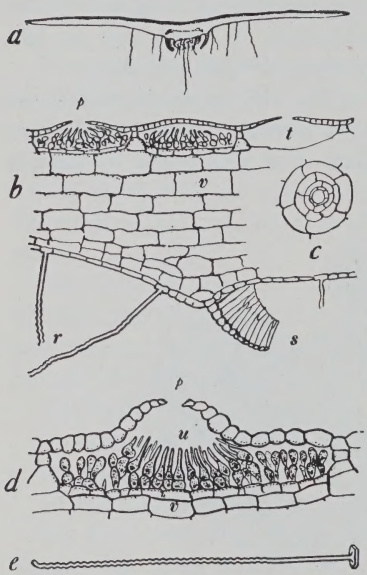



FIG. 26. Conocephalus. ***a***, cross section of the thallus, showing rhizoids and scales beneath; ***b***, a bit of the same more enlarged; *p*, breathing pore in the upper epidermis; *r*, rhizoids; *s*, scale; *t*, one of the areas about a pore (empty); *v*, common parenchyma; ***c***, a breathing pore, as seen from the surface; ***d***, details of a single area; *p*, pore; *u*, assimilatory parenchyma; *v*, common parenchyma. ***e***, a single entire rhizoid cell.

An examination of a cross section of the thallus, fig. 26, *a*, *b*, shows clearly the relation of parts. The thallus is a large aggregate of cells, and the cells are highly differentiated. They form two principal kinds of tissue: —

**Epidermis,** of flat transparent cells that cover the whole exterior, some of which are modified slightly in shape to form the borders of the breathing pores, and others are modified very greatly, being extended into long filaments, to form the rhizoids (fig. 26, ***b***, ***e***).

**Parenchyma,** of softer cells, richer in protoplasm, filling the whole interior and differentiated into two principal sorts (fig. 26, ***d***, *u* and *v*): —

1. *Assimilatory parenchyma* of smaller, thin walled cells,

containing abundant chlorophyl, and situated in an upper stratum where they are in communication with the air through the pores, and with sunlight, which penetrates the transparent epidermis. These differ among themselves in form according to their situation.

2. *Common parenchyma*, of bulky, colorless cells composing the thicker interior stratum, which gives form to the thallus. A few common parenchyma cells rise as partitions between groups of assimilatory cells to mark out the areas already seen from the surface.

These are the primary tissues of all the higher plants.

Such integration of cells into a unit organism of mutually dependent parts, we have not found before. In the algæ we have studied, the cells are more loosely associated together, less differentiated, and physiologically more independent. When every cell is in contact with the water that contains its food, there is no need of special feeding organs.

But with the assumption of terrestrial life division of labor has taken place among the cells of the liverwort. Different plant functions are assumed by different groups of cells; that of getting carbon from the air by the cells of the assimilatory parenchyma; that of getting the mineral matters from the soil, mainly by the rhizoid cells; that of protecting the protoplasm from the new peril of evaporation, by the cells of the epidermis, etc.; each group doubtless improving in capacity for its special work, as it is relieved of the work now performed by other cell groups.

Cell division is localized in the liverworts, and in all the higher plants. It occurs in Conocephalus only at growing points located in the notched tips of the stem and branches. There new cells are formed during the growing season. They are at first minute and rich in protoplasm. They

rapidly increase in size and differentiate into the kinds of tissue just described, and take their places, to remain of constant form until the death of the thallus.

Reproductive cells are produced by another kind of differentiation from the growing points. On some of the branches, sperm cells and egg cells are developed in special receptacles (*gonangia*). The container for the sperms is called (as in plants generally) the *antheridium*.[1] A number of antheridia are immersed together in the top of a disc-shaped receptacle, (the antheridial disc or *antheridiophore*, fig. 27, *a*, *b*). The container for the egg is called an *archegonium*.[2]

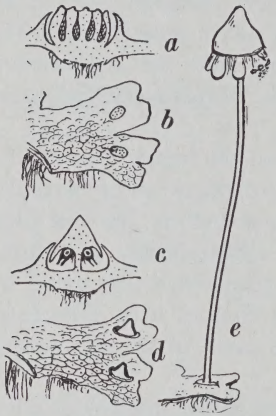



FIG. 27. Conocephalus. *a*, antheridial disc, showing antheridia in vertical section; *b*, the same in surface view; *c*, archegoniophore, showing archegonia in vertical section; *d*, the same in surface view; *e*, the mature archegonial disc, bearing sporophytes (one opened and shedding the spores).

Archegonia are developed upon a receptacle (*archegoniophore*) of a nature similar to, but of a form very different from that which bears the antheridia. It is a conic-capped, mushroom-shaped organ (fig. 27, *c*, *d*). The archegonia are inserted underneath the cap. Each archegonium (fig. 28, *A*) is a hollow, flask-shaped organ; the swollen base of the flask (which contains the single egg cell) is immersed in the tissues of the cap, and the open neck of the flask is directed downward.

During the fall and winter the disc is low and inconspicu-

[1] This is the equivalent of the better term *spermary*. It is in almost universal use in botanical textbooks.

[2] A special botanical term for one type of ovary.

ous, being contained in a circular pit in the top of the thallus, with only the conic cap projecting. It is surrounded by a circular cleft which admits of access to the archegonia when these are mature. The sperms are free-swimming cells of strictly aquatic habit. They can make their egress from the antheridia and swim about to find the egg cells only when rain or dew has supplied sufficient water for the purpose.

In early spring the stalk of the archegonial disc elongates enormously and pushes the cap up in the air to a height of two or three inches (fig. 27, *e*). This lengthening is not brought about by the production of new cells, but by the further development of those already present. In the center of the transparent stalk may be seen an axial bundle of cells that have become extraordinarily lengthened, and that form, when fully developed and hollow, a bundle of capillary tubes; these facilitate the transport of food materials from the thallus below to the maturing spores above.

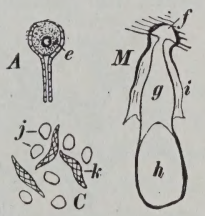



FIG. 28. Conocephalus, *A*, archegonium in vertical section; *e*, egg cell; *M*, the sporophyte; *f*, foot; *g*, stalk; *h*, sporangium; *C*, contents of sporangium; *j*, spores; *k*, elaters.

**Development.** — From the fertilized egg cell there develops, not another thallus like the one that produced it, but a plant body of a very different sort (fig. 28, *M*), called a *sporophyte* (or *sporogonium*). This develops as follows: The egg cell divides repeatedly, forming a mass of cells that distends the walls of the archegonium. This cell mass then differentiates gradually into the three parts of the sporophyte, *foot*, *stalk* and *sporangium*. The sporophyte develops at the expense of the archegoniophore; its foot remains immersed in the tissues surrounding the base of the archegonium, and

serves as the food-absorbing organ. The stalk gradually elongates and pushes the sporangium downward toward the outer world. The sporangium develops a protective outer wall, and the cell mass contained in it finally develops into a very great number of minute roundish reproductive cells called *spores*, intermixed with sterile cells called, because of their function, *elaters*. Upon the drying and bursting of the sporangium wall, the elaters, by their twisting and turning, assist in the scattering of the spores.

**Alternation of generations.** — From those spores which, when scattered abroad, find suitable lodgment and food for growth, there develop new thalli, like the one with which we started. Thus there are two distinct parts to the life cycle of Conocephalus; a large independently-feeding green plant, which, because it produces the sex cells (*gametes*) is called the *gametophyte*, and a small, dependent sporophyte producing the spores. The former is a sexual, the latter an asexual generation. This phenomenon is known as *alternation of generations*. Because of its importance in the green plant series, gametophyte and sporophyte should be clearly distinguished at once. Whatever the form assumed, the gametophyte produces the gametes, the eggs and sperms. The sporophyte produces the spores; the one regularly develops from the reproductive cells produced by the other.

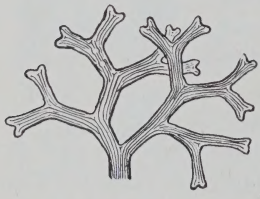


FIG. 29. A spray of the floating liverwort, *Riccia fluitans*.

**Other bryophytes.** — *Riccia* (fig. 29) is a simpler liverwort, that has the archegonia and antheridia immersed in the upper side of the thallus. *Jungermannia* (fig. 30) is a liverwort of more highly specialized form, in which the midrib of the thallus has become the plant stem, and the broad

margins have become differentiated into leaves. These, however, are rather crude in form and simple in structure, lacking veins and even a midrib, and consisting of a single layer of chlorophyl-bearing cells. They indicate relationship with the mosses.

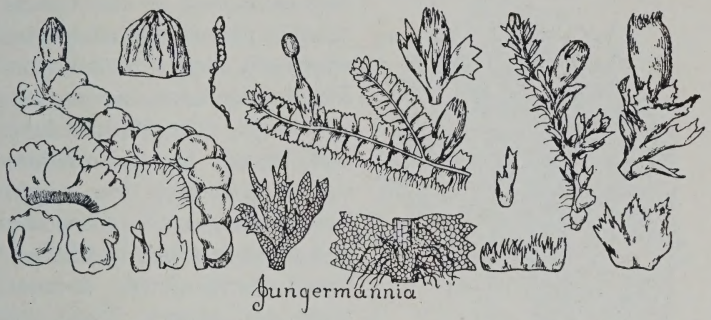



FIG. 30. Three leafy liverworts, Jungermannia; three species. (Copied from an early edition of Gray's Manual of Botany, a classical old manual of North American plants.)

**The sporophyte phase in bryophytes.** — It is in this group we first find alternation of generations fully established with a well developed sporophyte. While there is reproduction by means of both sex cells and spores among the thallophytes, there is rarely the regular alternation between them and never such differentiation of a distinct sporophyte phase as we find here.

This phase finds a simple expression in Riccia. From the egg there develops a single spherical shell of sterile cells containing spores (Fig. 31) only. No foot nor stalk appear; only sporangium: and in the sporangium, no sterile cells; only spores.

**Mosses.** — The greatest development of sporophyte phase in these plants is found in the mosses. The archegonia are terminal. From the fertilized egg there develops a sporophyte

of great length which early ruptures the archegonium wall, carrying the upper end of it up into view as the *calyptra*. This falls away at maturity. Foot, stalk and sporangium are highly differentiated. The foot is buried in the tissues of the parent gametophyte, whence it draws nourishment for development, as in the liverworts. The stalk is long and pushes the sporangium up conspicuously into view. The sporangium is composed of a number of highly differentiated sterile parts. It contains no elaters, and the spores are situated in a cylindric layer surrounding a central core of parenchyma cells (called the *columella*), and usually covered over by a detachable cap, the *operculum*, that grows beneath the calyptra and is a part of the sporangium itself (fig. 32). Underneath the operculum there is often a peripheral row of teeth attached at the margin, with free tips that meet at the center of the columella. These regulate the dispersal of the spores, by lifting (as if by hinges at their bases) when dry, and exposing the top of the spore cavity, allowing the spores to be shaken or to fall out, and closing down by hygroscopic movement when wet.

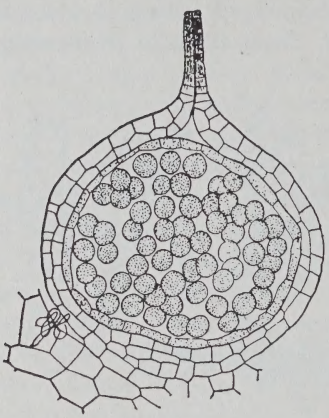


FIG. 31. Section of the simple sporophyte of *Riccia natans*, inclosed within the distended wall of the archegonium. Note that all the cells of the sporophyte are spores save a single peripheral layer that is dotted in the figure (after Chamberlain).

Perhaps the most significant (prophetic) feature is the appearance of a loose layer of chlorophyl-bearing parenchyma in the outer wall of the sporangium, and the development in the epidermis covering the base of it, of a few breathing pores

(stomates) of a new type. This type is the prevailing one in the following groups of plants. Thus the sporophyte is able to gather some carbon for itself, though dependent on the gametophyte for other elements of its food.

We have already seen that, as compared with the algæ, the bryophytes have attained to a higher grade of bodily structure, and have acquired an organization that is directly related to terrestrial life. The new features of their life history, also, are related to this changed environment. They brought with them from the water and have one and all retained a strictly aquatic mode of fertilization. All have free-swimming sperm cells: and the distance between the antheridia and the archegonia must be traversed by water at the time the sex cells ripen; else, fertilization cannot take place. But spores do not require to be fertilized: and the introduction of the spore-producing generation seems to have been the means availed of for securing the production and distribution of a host of new individuals while avoiding the exigencies of fertilization under the changed conditions.

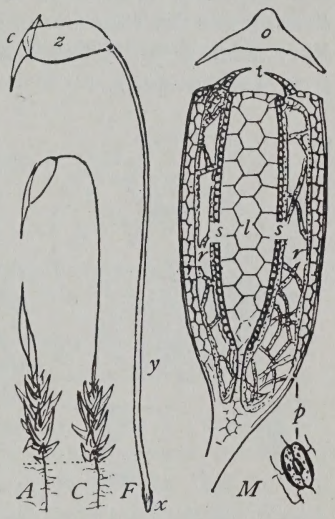



FIG. 32. The moss sporophyte, *A*, *C*, *F*, successive stages in its development; *c*, calyptra (detached top of archegonium); *x*, foot; *y*, stalk; *z*, sporangium; *M*, longitudinal section of the sporangium; *o*, operculum (detached); *l*, columella; *r*, respiratory parenchyma; *s*, spores; *t*, teeth; *p*, breathing pore (stomate), and the same below in surface view.

Mosses are the dominant bryophytes. Their stems are leafy, and often rise erect, and contain a central cylinder

of long capillary water-conducting cells. Their leaves are better developed, possessing a midrib, and usually a marginal row of close-knit cells. Their rhizoids are larger and are composed of several cells.

When the moss spore germinates it produces first a cylindric greenish, branching, alga-like filament (called a *protonema*) and from the tips of short lateral branches of this the leafy stems arise. Thus a number of moss plants may arise from a single spore.

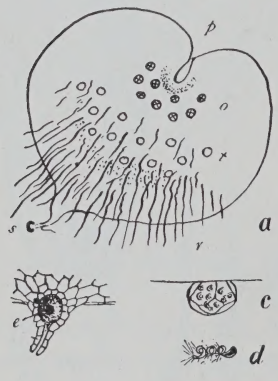



FIG. 33. The fern. *a*, the gametophyte phase, inverted and seen from lower surface; *s*, the spore from which it grew; *r*, rhizoids; *p*, the growing point in the bottom of the apical notch; *o*, archegonia and *t*, antheridia; *b*, a single archegonium in vertical section; *e*, egg cell; *c*, a single antheridium, with developing sperm cells; *d*, a single mature sperm cell.

## II. PTERIDOPHYTES

### FERNS, HORSETAILS, ETC.

These are plants of larger size than bryophytes, and of still greater diversity of appearance. They differ most remarkably in the size and predominance to which the sporophyte has attained.

**The fern** (Pteris). — The gametophyte of the fern will serve well to connect with preceding studies. It is a little heart-shaped thallus (called the *prothallium*), hardly exceeding a quarter of an inch in diameter when grown. Its structure is even more simple than that of the thallus of a liverwort. There is the same copious development of rhizoids, connecting it with the soil, but there is less differentiation of the tissues of the thallus itself, there being no sharp distinction of special assimilatory parenchyma, and no pores. The

growing point is in the notched tip, protected as before by the lobes extended at either side of it. The archegonia and antheridia are developed on the under side of the thallus, and open downward; the former are arranged in a cluster, nearer the growing point (fig. 33). The sperms are motile and swim about when mature, if favoring rain or dew give them opportunity. Many of them mature in advance of the maturing of the eggs of the same thallus, thus favoring cross-fertilization, since they must then find their mates on other prothallia.

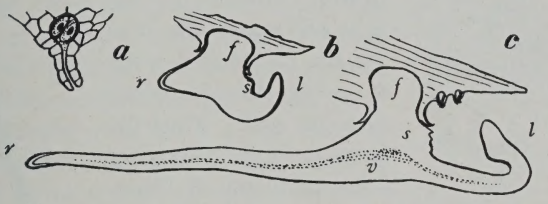



FIG. 34. Fern embryos. *a*, after the first division into two cells; *b*, an embryo showing the beginnings of root (*r*), stem (*s*) and leaf (*l*); *c*, an older embryo, the leaf tip turning upward, vascular bundles (*v*), developing; *f*, foot.

Thus, it will be seen there is quite a general similarity between the prothallium of the fern and the thallus of a simple liverwort. But this phase of the fern is least developed, and the sporophyte phase is, save in its origin, exceedingly different. The comparison of sporophytes will, therefore, be more readily made if it be a comparison of early stages.

**The sporophyte.** — The fertilized egg divides (fig. 34, *a*) and produces a mass of cells within the walls of the archegonium. From this cell mass there are early differentiated a number of parts, one of which clearly corresponds to the foot of such sporophytes as we have seen hitherto, it being a food-absorbing organ immersed in the tissues of the parent gametophyte (fig. 34, *f*). From the remainder (which corresponds

only in a general way to the stalk) root and leaf develop, the root extending downward into the soil, branching and developing rhizoids for independent foraging there, the leaf passing out between the lobes at the apex of the thallus and turning upward to the light and expanding, taking up its proper work of carbon dioxide reduction (fig. 35). Thus the sporophyte early acquires a complete set of foraging organs and becomes independent of the parent gametophyte. The body of the embryo grows out more slowly into the underground horizontal stem (rhizome) of the fern, producing as it grows new leaves that rise to the light, and for a time increase in size and complexity, and new and larger roots that spread through the soil. So, the sporophyte is launched upon its career of independent existence; and, not being limited to the supply of food that a small parent thallus can furnish, spore production is long delayed. A long growth period intervenes. A large plant body is pro-

FIG. 35. The fern sporophyte, in the first leaf, but still attached to the parent gametophyte.

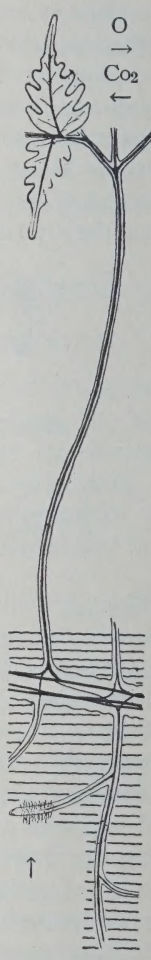



FIG. 36. Diagram illustrating the intake of food materials at root and leaf in the fern, and the transportation system of vascular bundles connecting the two sources of supply with all parts of the plant body.

duced, which when mature develops sporangia in extraordinary numbers upon the surface of its leaves.

In this plant body the food absorbing organs are those with which we have already become acquainted in the bryophytes. The rhizoids surround the tips of the rootlets in the soil (fig. 36). The assimilatory parenchyma is chiefly located in the leaves, protected by a layer of transparent epidermis, composed of thin, flat, curiously interlocking cells (fig. 37). The oxygen of the air finds ingress through pores (stomates) of the sort already seen in the moss sporophyte (fig. 32, ***M***, *p*).

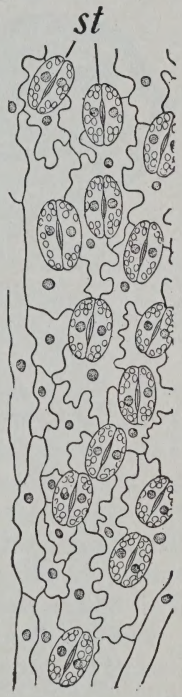



FIG. 37. Leaf epidermis of the fern; *st*, stomates or leaf pores.

The development of a plant body of so greatly increased size is made possible by the development of new structures out of the parenchyma. These are of two sorts: —

*Supporting tissues*, necessitated by increasing size and weight.

*Conducting tissues*, necessitated by the increased distance between the two sources of intake of food materials, the rhizoids deep in the soil, and the assimilatory parenchyma of the leaf, lifted high in the air.

The position of these new parts in the plant body can best be learned by an examination of the structure of the mature stem in a cross section of which (fig. 38) they may be seen with the unaided eye. As before, the surface layer of cells is epidermis, and the whole of the soft part of the interior is parenchyma. The new tissues whose function is chiefly or

wholly supportive are more or less brownish in color and arranged (1) in a peripheral layer just beneath the epidermis, and (2) in two or more broad, darker colored strands of tissue extending through the midst of the parenchyma. These tissues consist of thickened and closely united walls of empty cells. The inner darker strands may readily be traced through the soft parenchyma, and followed where they branch out into the bases of roots and leaves.

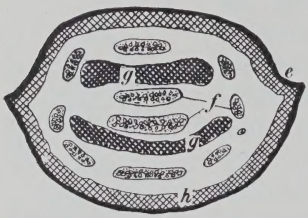



FIG. 38. Diagram of a cross section of the underground stem (*rhizome*) of the fern (Pteris). *e*, epidermis; *f*, vascular bundles; *g*, inner strands of supporting tissue (*sclerenchyma*); *h*, peripheral layer of supporting tissue.

The tissues whose most important function is the conduction of food materials (though certain of their elements also serve for support) are found in the vascular bundles. These, also, are readily seen in cross section of the stem. They are of various sizes, and not constant in number, but are easily recognizable by the finely perforate appearance that the cut end of each bundle presents. These bundles, like the internal strands of supporting tissue, may be traced through the soft parenchyma by dissection, and followed at their branchings out into the base of roots and leaves.

**Vascular Bundles.** — These bundles constitute the transportation system of the sporophyte. They condition its growth, enable it to take possession of larger areas and deeper layers of soil, to rise higher and to spread out more widely in the air and light, and are, therefore, structures of first importance in the fern. They are compound structures formed out of the common undifferentiated tissue (called the *meristem*) by the processes of cell growth and differentiation. They are made up of a variety of tissues (fig. 39).

The most important conducting tissues are two: (1) *tracheids*, the tubes of the largest diameter which give the perforate appearance to the cross section of the bundle; these are

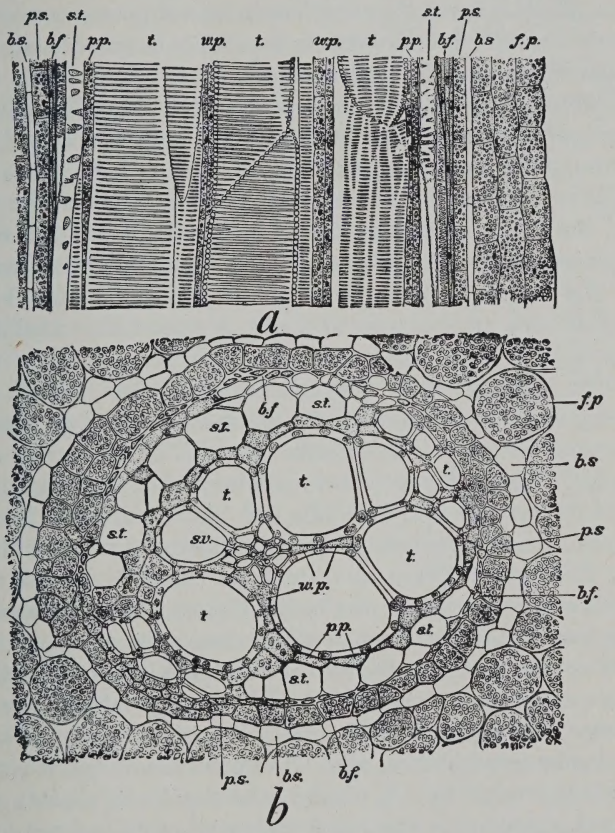



FIG. 39. Vascular bundle of the fern (Pteris) after Sedgwick and Wilson. *a*, longitudinal section; *b*, cross section; *f p* common parenchyma; *b s*, bundle sheath, *p s*, phlœm sheath of parenchyma; *b f*, bast fibres; *s t*, sieve tubes; *p p*, phlœm parenchyma; *t*, tracheids (wood tubes); *w p*, wood parenchyma; *s v*, spiral vessel.

the lignified walls of elongated and empty cells, and serve chiefly for the conduction of water, with whatever may be dissolved in it. (2) *sieve tubes:* these are living, greatly elongated, extensively vacuolated, but yet protoplasmic cells, with oblique overlapping ends. The opposed end walls exhibit groups of fine perforations. Through the latter there is protoplasmic continuity between adjacent cells. Albuminoid substances are distributed through these cells by diffusion through the continuous protoplasm.

The chief supporting tissues of the bundles are two: (1) the tracheids already mentioned, and (2) the bast fibres, situated nearer the periphery of the bundle. The remainder of the bundle is parenchyma, little differentiated. It constitutes the packing, so to speak, between the other more specialized parts. (See figure 39.)

The distribution of the bundles themselves is such that every considerable part of the plant body is put in vascular communication with every other part. The differentiation of vessels follows closely every growing point, down into root and rootlet, up into leafstalk and blade and lobe, through every vein and veinlet. Some branchlet of a vessel ends not far from every group of rhizoids in the soil, not far away from every stomate in the leaf. The venation of the leaf is the map of the distribution of the vessels therein.

The new organs of the fern are root and leaf, both of them, mere extensions of the plant body, carrying out into new and wider foraging ground the original foraging organs, rhizoids and chlorophyl-bearing cells. The moss has no better circulatory apparatus than a simple axial bundle of slightly elongated parenchyma cells; it develops no roots and can forage in the soil only the length of its rhizoids. Clearly, the structures of the fern we have just noted sufficiently account for the larger size to which the pteridophytes have attained.

**Spore formation** is greatly delayed, but in the end it occurs on a much larger scale by reason of the large plant body built up and capable of nourishing spores; moreover, it may be repeated by the same sporophyte year after year. In the bracken fern, sporangia (fig. 40) are developed under the rolled margin of the leaf, in small clusters (called *sori*). Each sporangium is borne on a slender pedicel; its walls are composed of thin epidermal cells; one line of these cells, encircling the top of the sporangium, is differentiated into a ring (the *annulus*) of thick-walled hygroscopic cells, which at maturity burst the capsule by their elasticity, scattering the spores. The spores which fall in suitable place germinate after the manner shown in fig. 41, and grow into thin, flat, heart-shaped prothallia.

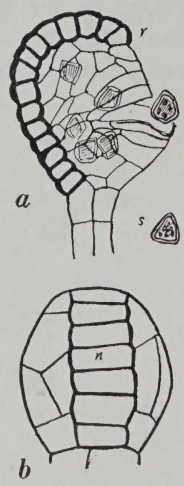



FIG. 40. Sporangium and spores of a fern, *a*, side view; *b*, rear view; *n*, the *annulus*; *r*, its front end, which lifts on drying and ruptures the wall below; *s*, a spore.

Comparing fern and liverwort, we see great similarity in reproductive organs and methods, considerable similarity in the gametophyte phase, and great divergence in form, size, structure and manner of life of the sporophyte.

**Other pteridophytes.** — The common horsetail (*Equisetum*) will serve to illustrate the kind of differences presented by another group of pteridophytes. The sporophyte phase of the horsetail is leafless, but bears green naked branches which arise from an underground rhizome. The chlorophyll-bearing parenchyma is located in the furrows of the branches. The furrows extend up and down, and the

chlorophyl-bearing cells communicate with the air by pores or stomates arranged in two rows in each furrow. The supporting tissues (aside from the unusually stiff epidermis) are located in the ridges, which they chiefly compose. The branches are hollow, and the vascular bundles are arranged

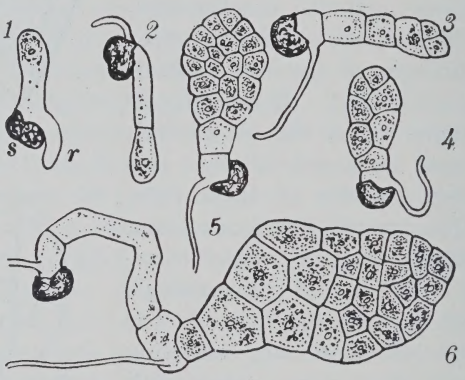



FIG. 41. Early development of the fern gametophyte from the spore; figs. 1 to 6 show successive stages; figs. 3 and 4 show the establishment of an apical cell and growing point; fig. 6 shows second rhizoid.

radially around the main central cavity, opposite the ridges upon the surface. Each branch is divided into segments by a series of nodes (at which it breaks when pulled, whence the popular name, " joint-grass "). The arrangement of ridges and valleys, of vascular bundles and cavities, of green respiratory parenchyma in the valleys and the broad bands of supporting tissue in the ridges, are readily seen in cross sections of fresh stems. The epidermis is covered with secreted nodules of silica which render the branches rough to the touch (whence the popular name " scouring-rush ").

The spores are developed in numerous sporangia that grow underneath the scales of a fruiting cone (fig. 42, *a*, *b*, *c*)

at the top of the stem, as indicated. The outer covering of each spore is split into four long involute strips, which serve as elaters, and, being exceedingly hygroscopic, these extend and roll up again with slight changes of moisture, and push the spores out of the sporangia.

**Two kinds of gametophytes.** — While the spores all look alike, some of them on germination develop into small prothallia which produce only antheridia and others grow into larger prothallia which produce the archegonia.

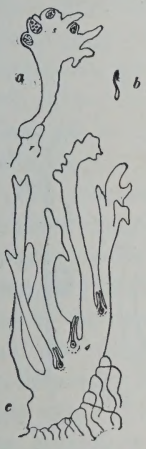



FIG. 43. Male and female prothallia of equisetum (after Goebel). *a*, the male prothallium, with marginal antheridia; *b*, a sperm cell; *c*, the female prothallium bearing three archegonia.

The prothallia (fig. 43) are therefore unisexual, as in some of the mosses, but each thallus and especially the male, is of very small size. Fertilization occurs with the aid of water for transport of the sperms as in the fern, and the development of the sporophyte from the fertilized egg follows the same general course.

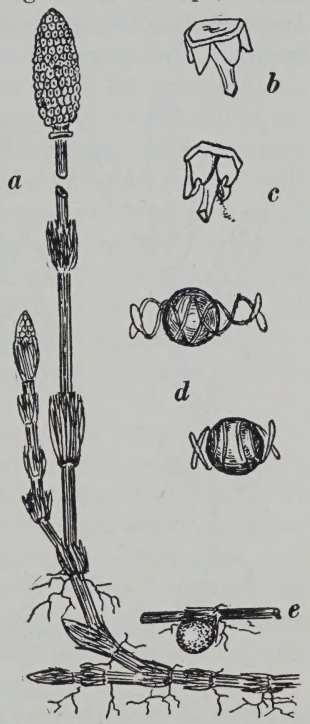



FIG. 42. The common equisetum (*E. arvense*). *a*, a fruiting spray; *b* and *c*, two scales from the fruiting cone, showing marginal sporangia; *d*, two spores, with their hygroscopic elaters partly unrolled; *e*, a bit of underground stem, bearing a round tuber.

**Selaginella** (fig. 44) is another pteridophyte with a trailing stem bearing small two-ranked leaves and lesser scales. It is especially interesting on account of the development of its spores. The sporangia are located in the axils of scales

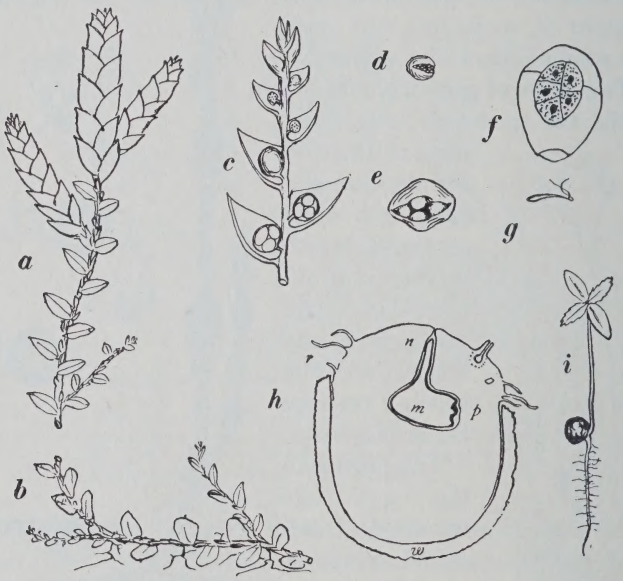



FIG. 44. Selaginella. *a* and *b*, tip and base of a fruiting spray; *c*, diagram of a fruiting spike, showing macro- and micro-sporangia in the axils of scales; *d*, microsporangium; *e*, macrosporangium; *f*, the male prothallium, spore mother cells dotted; *g*, a single sperm cell; *h*, the female prothallium, rupturing the wall (*w*) of the macrospore; *m*, a new sporophyte embryo; *n*, its suspensor, and *p* its growing point; *o*, the remains of an old abortive archegonium; *r*, rhizoids (greatly enlarged); *i*, the new sporophyte, still attached to the parent macrospore, with root and leaves already well developed (natural size).

aggregated in several terminal laterally flattened spikes and are of two sorts, large (*macrosporangia*), and small (*microsporangia*). The spores within them are of two sorts, large ones (macrospores), four in number developed

in the macrosporangia, and small ones (microspores) developed in large numbers in the microsporangia. It is less surprising, therefore, that there should develop from them two sorts of prothallia; but the prothallia themselves are very different from those we have studied hitherto.

The microspore develops, beginning while still within the microsporangium, into a male prothallium of microscopic size. It consists when mature of but few cells, one of these representing the body of the prothallium and the others the antheridial wall, inclosing a considerable number of sperm cells. There are no rhizoids or other nutritive organs developed, and the prothallium is short lived. After a few cell divisions it differentiates the sperm cells, which are liberated in the water by the dissolution of the surrounding cells.

The macrospore likewise begins its development while in the sporangium. It contains, however, within its own wall a large store of food material, upon which considerable development is possible. The spore divides repeatedly, and growing at the expense of the stored food, bursts the spore wall, and protrudes as a small prothallium which develops a few rudimentary rhizoids, and later a few archegonia containing egg cells. These are developed and often fertilized before the growth of the prothallium is complete.

The fertilized egg develops foot, stem, root and leaf as before, and in addition a special embryonic organ, the so-called suspensor, whose function it seems to be to keep the embryo pushed down against the prothallial tissue from which it must obtain its food. By the time this supply is exhausted the embryo has developed a root, bearing rhizoids, and one or two pairs of minute leaves at the apex of the stem, and is ready to get food for itself independently.

The predominance of the sporophyte phase is, in this

plant, very marked. The gametophyte is here not only reduced in size, but wholly dependent on the antecedent sporophyte for food — a reversal of the conditions found in the Bryophytes.

## III. SPERMATOPHYTES

### Seed Plants, or Flowering Plants

These are the dominant land plants of our own time. Bryophytes and Pteridophytes we find by searching, but spermatophytes fill the landscape.

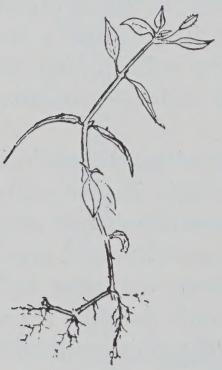


Fig. 45. Chickweed.

Like the preceding group they present utmost diversity in form and appearance and only agree in a few fundamentals of life history. The gametophyte phase is so reduced and difficult of study that we will suit our convenience by beginning with the sporophyte phase — the leafy plant, which, as with the preceding group, is the phase we ordinarily see.

Any familiar herb will show how much the sporophytes of the two groups have in common. Here is the little chickweed (fig. 45) that springs up from self-sown seed in our lawns, and grows about the foundation of our buildings on the shady side. It is a *dicotyledon*, which is to say that its seed on germination first produced two seed leaves (cotyledons).

The differentiation of the plant body into root stem and leaf is as we have seen it in the pteridophytes. The plant body of the chickweed is covered over with epidermis, some of whose cells develop in the air into plant hairs and in the

soil into rhizoids. If we strip a bit of epidermis from a leaf we find its constituent cells, and the guard cells of the breathing pores to be of the same type as in the fern leaf. If we section the leaf (fig. 46), we find in it the same tissues: there are stomates in both layers of epidermis and there are intercommunicating air spaces

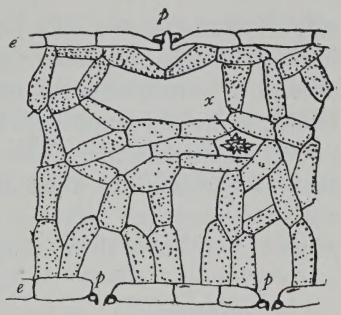



FIG. 46. Cross section of a bit of chickweed leaf, *p*, *p*, *p*, pores; *e*, *e*, epidermis; *x*, crystal (probably of oxalate of lime).

throughout the interior of the leaf. Here and there are minute vascular bundles in the midst of the parenchyma.

In a cross section of the stem there appear some differences of importance (fig. 47, *a*). Epidermis covers it and parenchyma fills most of the interior as before, but the arrangement of the vascular bundles is very different. There is hardly any development of supporting tissue out-

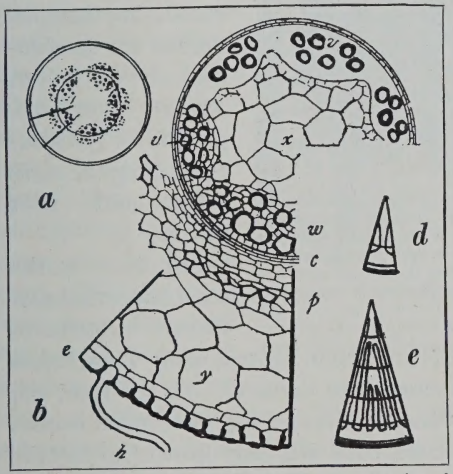



FIG. 47. Diagrams of stem sections. *a*, cross section of chickweed stem, the inner circle representing the cambium ring, the two radial lines include the portion enlarged in *b*.

*b*, an enlarged portion of *a*, including the cambium ring and pith and one complete vascular bundle; *e*, epidermis; *h*, hair, *c*, cambium separating between *p*, phloem and *w*, woody portions of bundles; *v*, spiral vessels in the woody portion; *x*, pith; *y*, common parenchyma of bark.

*d*, one-year-, and *e*, four-year-old woody stems, illustrating the increase of vascular bundles. See also figure 49.

side of the vascular bundles, and these are very weak in a trailing herb like the chickweed. The bundles are arrayed in a ring around a central core of parenchyma (the *pith*), and each bundle is divided lengthwise by a thin sheet of growing tissue known as the *cambium*. This cambium cylinder divides the stem as a whole into inner and outer portions that are familiar to every one who has peeled a rod or made a willow whistle; we know them as bark and wood. The cambium divides each bundle of the entire circle into an inner woody portion (*xylem*), containing the open vessels for the conduction of water, and an outer bark portion (*phloem*) containing the sieve tubes and bast fibers.

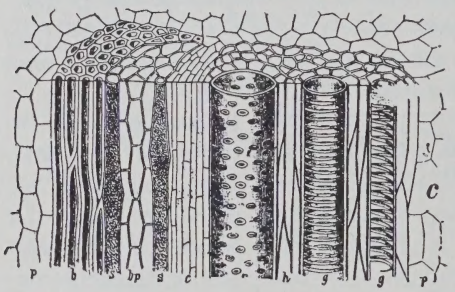



FIG. 48. Diagram of a section of a single vascular bundle of a golden-rod stem, showing the enveloping parenchyma (*p*, *p*) and in the bundle itself, from left to right, bast fibers (*b*), bast parenchyma (*bp*) a sieve tube (*s*), cambium (*c*), a large pitted vessel (*o*), wood fibres (*h*) and two spiral vessels (*g*, *g*): The last four are the elements of wood, (after Wettstein).

Cambium is the most important new feature in stems of this type. Its small cells are rich in protoplasm. They retain capacity for further increase by division. In the fern, cell increase occurs only at the stem apex; when the stem is once formed and its constituent cells are fully grown no further increase in diameter is possible. But cambium makes possible a continuance of stem enlargement. In woody plants it adds new cells each growing season to each of the tissue layers that it lies between.

**Bast.** — In the bark the sieve tubes serve as distribution channels for food assimilation products, as in the fern, and

bast fibers serve for support, but the latter in seed plants assume much greater importance. There is little development of bast fibres in soft stems of the chickweed; but in the stouter herbaceous stems of goldenrod (fig. 48) they form strong strands of fibre. Besides giving rigidity to the stem, they overlie and protect from injury the softer growing parts within.

Bast fibres attain great length, strength, and pliability in some plants. They become of commercial value as fiber products in such plants as flax, jute, and hemp. Linen is made from flax. In manufacture the bast fibers are separated from other tissues by first rotting (retting) and then breaking the stems, then beating and combing the fragments of the brittle wood and other waste away from the bast. Further combing to separate the longest fibres, and bleaching prepare the bast, for its fibres are nearly pure cellulose. From it are made the strongest threads and twines, and the finest laces.

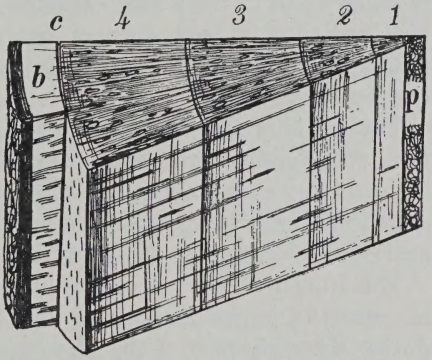



FIG. 49. Segment of a four-year-old woody stem, with bark (*b*) in part removed; *c*, cambium; *p*, pith; *1*, *2*, *3*, *4*, wood of the four years growth; vertical surface shows wood fibers overlaid by transverse fibers of the medullary rays.

**Wood.** — Rigidity of stem is secured by further development of the xylem elements of the vascular bundles, by increase in the number of the bundles, and by their consolidation in a ring of wood underlying the cambium. In figure 47 at *d* and *e* the growth of wood by added annual increments is

diagrammatically indicated. This will be better understood from the careful study of the stem of any woody plant such as the pine (fig. 49). Here the cambium layer clearly delimits bark and wood. All the packing-cells of common parenchyma intermixed with the xylem have been transformed into wood fibers; those inside the bundles have been elongated lengthwise of the stem, and fill solidly the interstices between the large pitted vessels; those between the bundles have been elongated at right angles to the others and form the radiating *medullary rays* of the wood. The trunk of the pine tree splits best radially, in the plane of the medullary rays. It is patches of medullary rays that give beauty of grain to quarter-sawed oak.

The vascular bundles become wedge shaped in cross section, and closely compressed. Thus, there is formed beneath the cambium a ring of wood, that owes its solidity to the close adhesion of cells having lignified walls, and the beauty of its grain to the arrangement of the cell groups.

The annual rings of wood are formed by the development of vessels of larger diameter in the " spring wood " formed during the early part of the growing season. As new layers of wood are added outside, those first formed become changed from " sap wood " into " heart wood," losing their capacity for conducting water. That the heart wood is not essential to the life of the tree, every hollow tree testifies. That the outer layers are essential is shown by the fatality of "girdling" the trunks by cutting an encircling groove through the sapwood and bark.

**Monocotyledons.** — There is, however, one great group of seed plants, known as the Monocotyledons (the seed on germination producing but one seed leaf), that has not the mode of growth above described. Structurally these are much more like the pteridophytes in that they have no

cambium ring, and no axis of solid wood, but their bundles are scattered through a soft internal parenchyma, and the chief support of the stem is a stiffened cortex beneath the epidermis, comparable to the layer similarly situated in the rhizome of the fern (fig. 50).

Monocots are the grasses and sedges, the lilies and irises, and most other plants that have smooth-margined, parallel-veined leaves. These dominate considerable portions of the earth's surface, in prairies, steppes, savannas, marshes, and other unforested regions. In temperate climes the aërial stems of all of them are of annual growth, and the perennial roots and under-ground stems of the dominant species are not injured by fires that would hinder forest growth.

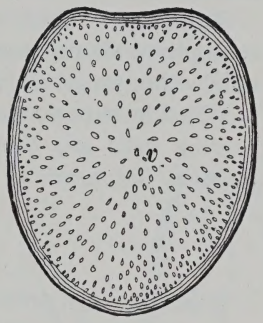


FIG. 50. Cross section of corn stalk, *c*, cortical layer; *v*, vessels scattered through the parenchyma.

When such plants grow to the size of trees as in the case of palms, their trunks consist of a sheaf of fibers embedded in pith. Upward growth is by additions only at the summit where the terminal bud is continually expanding. A cylindric shaft results, instead of a tapering trunk. A heavy crown of leaves is carried aloft at the top.

As in the fern, the vascular bundles contain both bast and wood; but these mixed elements may be strengthened and consolidated into fibers of great length and pliability, as in the manila hemp plant and the pineapple. These fibers being surrounded by soft parenchyma, their extraction is comparatively easy. The soft parts may be scraped from them with a dull knife.

On the other hand, these fibers may be consolidated with

the cortex to form sheets of tissue that are almost like wood, as in the hollow stems of bamboos. Such stems, strengthened by interlacing of fibers at the solid nodes, are marvels of mechanical efficiency. So, also, is the slender straw that bears aloft its heavy head of wheat.

**Summary.** — From this very brief sketch of the seed-plant sporophyte we may learn that the parts of the plant body are much the same as were found in pteridophytes — only modified in form and arrangement. Rhizoids and chlorophyl-bearing cells are the foraging agents still, and vascular bundles, the means of communication between them.

## Development

When we turn to the developmental side the differences are much greater. Flowers appear in the spermatophytes, and — what is vastly more important — seeds, also. Let us now study the manner in which seeds are developed.

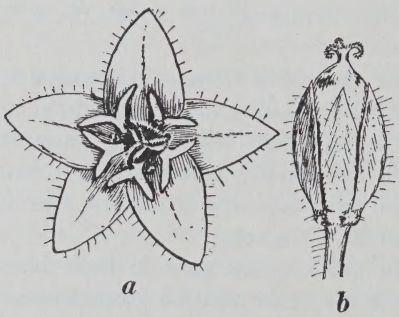



Fig. 51. Chickweed. *a*, flower; *b*, fruit.

Figure 51 shows at *a* the flower of the chickweed with its three stigma-tips alternating with three small stamens, and with five small white bifurcated petals wholly encompassed by a like number of big green sepals. At *b* in the figure, surrounded by the persistent sepals and surmounted by the stigmas, is shown the maturing fruit, within which the seeds are contained.

The differences between flowers of this type and the pteridophyte in reproductive methods are so great, that we will find it easier to study first the conditions existing in a more primitive seed plant, and afterward, those found in a highly developed flower. So let us examine first the pine, and after that the violet.

**Reproduction in the pine.** — In the pine we again meet with two kinds of spores, microspores and macrospores. The microspores of the seed plants have an older name: *pollen*

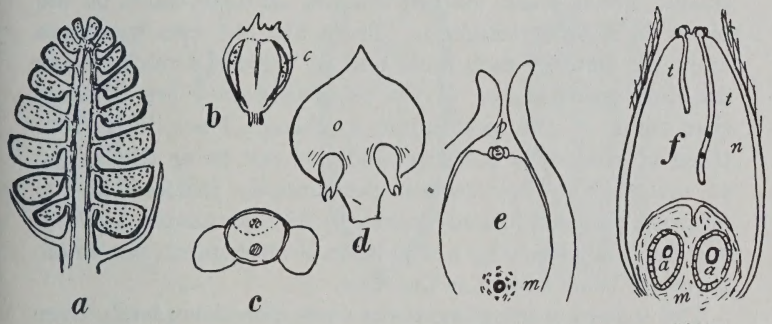



FIG. 52. Diagrams of spore development in the pine, *a*, longitudinal section of the small male (staminate) cone; *b*, one of the scales from the same, showing at *c*, the pollen cavities (microsporangia); *c*, the single pollen grain, divided into two cells, and bearing a pair of thin flat winged processes at its sides;

*d*, a scale from the female (pistillate) cone, bearing a pair of macrosporangia:

*e*, one of these in section, with a pollen grain lying inside the cavity, *p*, (micropyle) at the top; *m*, macrospore;

*f*, macrosporangium penetrated by two pollen tubes (*t*, *t*); two sperm nuclei (*n*) shown in one of them; the macrospore (*m*) is developed into the female prothallium, bearing archegonia (*a*, *a*) each containing an egg.

*grains;* the microsporangia in which they develop are the pollen sacs of the anthers. The latter are developed in pairs in the lateral margins of scales of the well known little cones (fig. 52, *a*), which shower down yellow pollen in early spring. Such cones are remotely comparable to the fruiting spikes of Selaginella and Equisetum.

The microspore or pollen grain develops into a male prothallium or gametophyte of extremely small size, consisting when grown of only a few cells, one of which on division gives rise to two sperm nuclei. These lack locomotor organs and do not swim abroad when mature; instead, the microspore (or the prothallium developed from it) is transported bodily by the wind to the vicinity of the egg cells.

The macrospores (fig. 52) are developed in similar fruiting spikes, which when mature are the familiar cones of the pines (and other *conifers*). There are but two sporangia upon the base of each scale and in these the macrospores are developed singly. As in selaginella they are of large size, owing to the food stored in them. They differ from those of selaginella most markedly in not being discharged at maturity. They remain permanently inclosed in the macrosporangium (usually known by its older name, *nucellus*), and invested closely by a thin layer of integument, the whole structure being known as the *ovule*.

The investing integument does not close completely over the macrosporangium, but leaves a little hole at one end, the *micropyle*. Hither the microspore is brought by the wind previous to fertilization.

The macrospore remains thus in captivity. Within it develops a mass of cells which is the female prothallium, in the apex of which adjacent to the micropyle several reduced archegonia are developed, and in each of these an egg nucleus is produced. The microspore, previously lodged at the micropyle, develops a rhizoid-like process (the *pollen tube*) from the antheridial cell, and this penetrates to the egg and liberates its sperm nuclei through its ruptured tip. One of these unites with the egg cell, effecting fertilization.

Then the embryo sporophyte of the new generation begins

to develop, also in captivity, within the wall of the old macrospore, and at the expense of the prothallial tissue which now fills it. As with the pteridophytes studied, but one embryo is developed; if several eggs are fertilized, one in developing gains the ascendency and crowds out the others. The form of the embryo is indicated in (fig. 53).

**The seed.** — After developing a little way the embryo enters upon a resting stage, the integument hardens about it

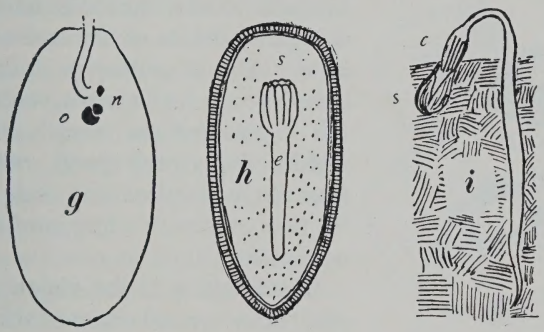



FIG. 53. Diagrams of development of the seed in the pine. *g*, a single archegonium, penetrated by the pollen tube from which the two sperm nuclei are liberated, one of them is uniting with the egg nucleus (*o*); *h*, the seed; *e*, the embryo, which develops from the fertilized egg; *s*, endosperm (remains of the gametophyte); *i*, the germinating seed; the sporophyte slipping off the old seed coat (*s*) after having consumed the endosperm that was contained in it.

into a seed coat, and the whole becomes a seed, and falls away to resume its development when it finds suitable conditions somewhere in the soil. The seed is thus a composite structure consisting of three parts of very different nature. The seed coat and macrosporangium wall are a part of the old sporophyte; the remains of the prothallial tissue within (known as *endosperm*) is gametophyte, and the embryo itself is the new sporophyte.

If this seem confusing, the way to make it clear is to inquire

what is the origin of each part. To learn what is gametophyte, learn what has developed from the spore.

**Gymnosperm and Angiosperm.** — The pine and the violet represent the two chief groups of seed plants, whose most salient characters are found in flower and fruit. The gymnosperms (*gymnos*, naked and *sperma*, seed) bear the ovules (and later the seeds) uncovered upon the surface of the scales of the cone. The angiosperms (*angios*, a closed vessel, and *sperma*, seed) have the ovules (or the seeds) included within the closed pistil, which is thus the equivalent of a scale of the fruiting cone with edges inrolled and coalescent.

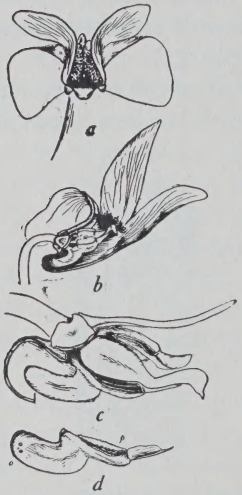



FIG. 54. Diagrams illustrating the structure of the flower of the violet (*Viola cucullata*). ***a***, a front view of the flower, with the lower saccate petal cut away, showing the barricade of hairs around and above the pistil.

***b***, lateral view with part of the sepals and petals removed.

***c***, the same more enlarged, and with the lateral stamens removed.

***d***, one of the two lower spurred stamens, with droplets of nectar shown on the outer side of the spur at *o* and a pollen cavity shown at *p*.

**Reproduction in the violet.** — The pistil is the central organ of the violet flowers, as in the chickweeds and in angiosperms generally. Its swollen base contains the ovules, with their macrosporangia, and this part, if fertilization occurs, will develop into the fruit. The surrounding parts of the flower are in fives. Closely applied about the pistil (fig. 54) are five stamens in a ring, each with two pollen sacs, opening internally as in the scale of the staminate cone of the pine. Then come five big petals, so showy they have given their color as a name to one of the seven colors of the spectrum. Outside the petals are five green sepals.

In figure 55 is shown a section of a more regular flower.

Pistil and stamens are the essential parts of the flower, since they produce macro- and microsporangia respectively. Petals and sepals are accessory parts. The showy petals, with a deep nectar sac on the lowermost, have a significance of their own in the matter of attracting insects to carry pollen from flower to flower, thus securing cross fertilization; but that is another story. We are here concerned only with the phenomena that lead directly to seed development.

The microspore (pollen) develops a male gametophyte of but two cells. One of these is very small (fig. 56, *b*); but from it are derived the two sperm nuclei. The other develops when it is carried to the moist

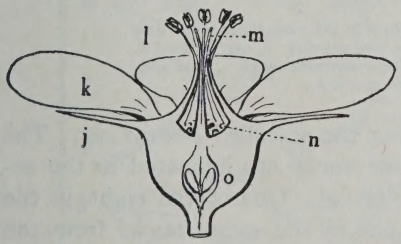



FIG. 55. Diagram of a section of an apple blossom: *j*, sepal; *k*, petal; *l*, anthers at the top of the stamens; *m*, stigmas at the top of the pistils; *n*, nectar droplets in the calyx cup; *o*, ovaries.

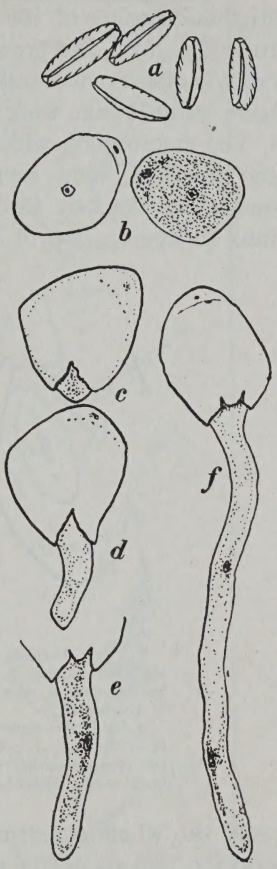



FIG. 56. The microspores of the violet and their development. *a*, dry pollen; *b*, the same wet with 15% sugar solution; *c*, *d*, *e*, *f*, development of the pollen tube in sugar solution; *c*, after 15 minutes; *e*, after an hour; one sperm nucleus shows in *f*.

stigmatic surface of the violet pistil, into a very long pollen tube (fig. 56). This grows down the style and enters the micropyle of the ovule and liberates the two sperm nuclei (that have escaped from their own cell wall) near the egg nucleus.

The macrospore, which is situated (as in the pine) within the nucellus, here surrounded by two investing integuments, develops by three successive divisions of its nucleus into an aggregation of eight nuclei within a distended cell

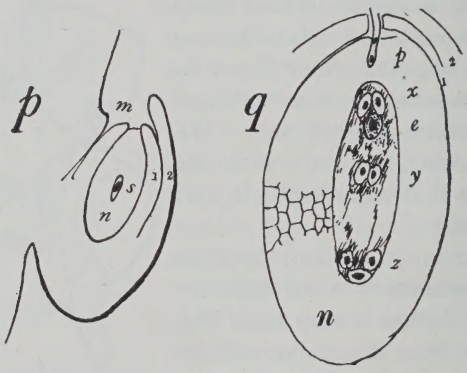



FIG. 57. Diagrams of development of the female gametophyte in the violet. *p*, a young ovule: *1* and *2*, inner and outer integuments; *m*, micropyle; *n*, macrosporangium (nucellus); *s*, macrospore;

*q*, the female gametophyte in the macrospore at the time of fertilization; *p*, pollen tube entering; *e*, egg nucleus; *x*, two synergid nuclei; *y*, two endosperm nuclei; *z*, three antipodal nuclei. Other lettering as in *p*.

wall, the whole constituting the so-called *embryo sac*. The position and names of these nuclei are indicated in the accompanying diagram (fig. 57, *q*). One of the eight is the egg nucleus, and with it one of the sperm nuclei from the entering pollen tube fuses. There is no archegonial wall. The remaining cells represent the body of the female prothallium, so far as developed at time of fertilization.

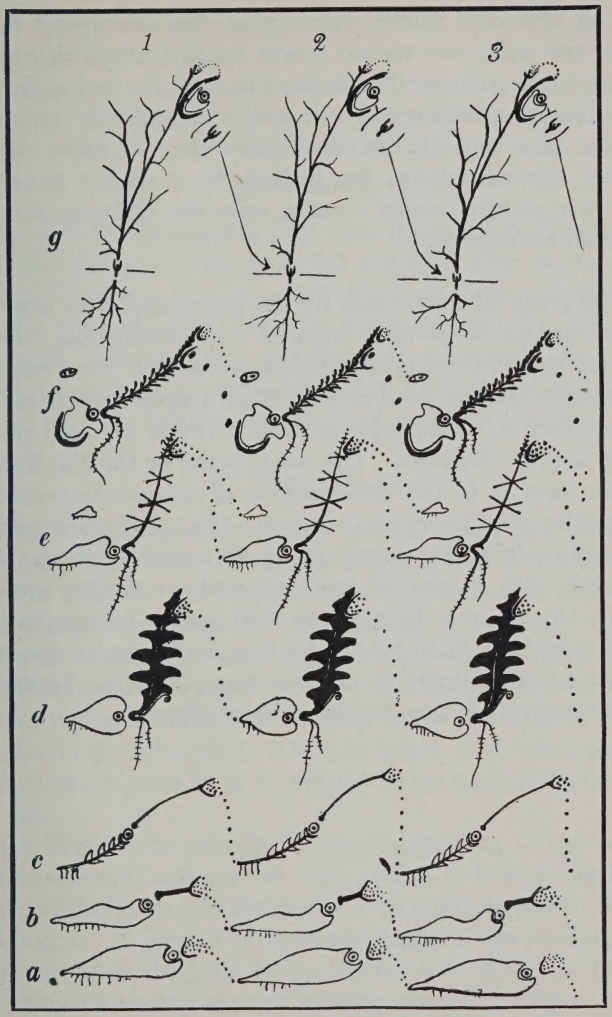



FIG. 58. Diagram, illustrating alternation of generations in the higher green plants. It is to be read from the bottom up. The horizontal lines of figures represent (*1*, *2*, *3*), successive generations; gametophyte is white and sporophyte is solid black; the egg is represented by circle with central dot, the spores are represented by black dots, of two sizes when differentiated. The types represented are: ***a***, a simple liverwort, (Riccia); ***b***, a more specialized liverwort, (Conocephalus); ***c***, a moss; ***d***, a fern; ***e***, a horsetail; ***f***, Selaginella and ***g***, a seed plant (seed in ( ) -marks, above).

The antipodal nuclei disintegrate, the endosperm nuclei fuse, and often the second sperm nucleus fuses with them, before undergoing further division to form the endosperm.

Subsequent development is wholly comparable with that of the pine already discussed, save that in many of the higher spermatophytes the endosperm is wholly absorbed, and the matured seeds contain only the embryo, and are without endosperm.

The great advance made by the spermatophytes over the lower groups is in their manner of reproduction. Bryophytes and Pteridophytes, though terrestrial, have retained an aquatic mode of fertilization. Their free-swimming sperms are subject to vicissitudes of drouth which the seed plants have largely obviated. The weak point in the life history of the fern is in the development of delicate unprotected prothallia from microscopic spores. The seed plant sets its offspring adrift only when grown to considerable size and supplied with a store of food material for further growth. What chance of a living have fern spores in competition with seeds? A main reason for the dominance of the seed plants upon the earth in our own time, therefore, lies in the better start in life they furnish to their offspring.

CHAPTER IV

# ANIMALS

Between the protozoans that were discussed in Chapter II and the metazoans (many-celled animals) now to be considered there is a wide gap. Intermediate forms are lacking. Among the metazoans there is great diversity of types of structure. We can here consider only a few of them. We select three, hydra, earthworm, and salamander, as being for us, who are vertebrates, the most significant types.

## I. The Hydra

This is a transparent aquatic animal about half an inch long that lives attached to stems and leaves in ponds and sluggish streams. It has a slender tubular body, provided with a disc-like *foot* at its basal end for attachment, and a circlet of *tentacles* surrounding a mouth at the other end. Both body and tentacles are very contractile, and become suddenly drawn down into a heap upon disturbance. On this account, although it is much larger than the animals studied in Chapter II, it is difficult to see while collecting in the field.

It is likely to be present on loose trash lying in any pond or slow stream, and a good way to find it is to bring in a pailful of this trash and distribute it in aquarium jars to stand over night. If present in numbers many of the hydras will move out upon the glass on the lighted side of the jar where they may be readily seen on looking toward the light. Too much trash in a single jar will obscure the view. Specimens

may be transferred to a watch glass or slide for study by scraping them loose from their support, and taking them up in a pipette, or better in a tube attached to a hand bulb.

In the aquarium hydras may be seen in any position, attached to the glass, or to the surface film of the water as well as to the stems; their bodies extended up or down or sidewise; their tentacles extended radially around the mouth. If fully extended, the tips of the tentacles hang vertically in the water and are very slender. These are hydra's fishing lines, set for passing water fleas, minute worms, etc., which they paralyze by contact; contracted, they are its arms, and are used for pushing the paralyzed prey into its mouth. Feeding is so slow a process, however, that if one be so fortunate as to see the prey captured he is likely to have to watch some time to see it swallowed. Often the body of a hydra is seen to be roundly distended in places by previously ingested food.

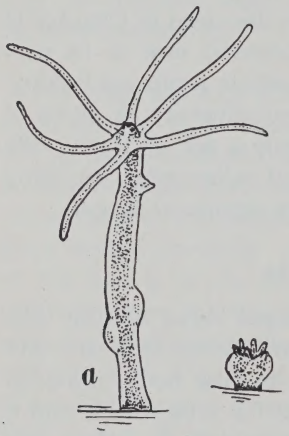



FIG. 59. A hydra. *a*, extended; *b*, contracted; spermary on the body above; *o*, ovaries below.

The hydra moves from place to place by turning end over end. It bends over in the desired direction, rests its tentacles on its support, lifts its foot and swings it over forward, attaches it and rises again. If the hydra be seen standing on its tentacles with its foot in the air, it is in the midst of one of these turns, which are made, not like hand springs, but with very great slowness. By this means it migrates to the lighted side of the jar. It also moves, but more

slowly, by alternate contractions and expansions of its foot, a sort of creeping progression.

When a number of hydras are present in an aquarium some of them are likely to show buds growing out from the side of the body. If several well grown buds be present on a single individual they make it appear somewhat more "hydra headed," since on the divided body there are then, if not heads, at least divergent tentacled tips. The buds, however, separate before they attain the full size of the parent.

Bud development may be traced in stages found in different individuals. First, there is an outpushing of the body wall in a little rounded knob; this elongates into tubular form; then it develops a whorl of tentacles that first appear as a circle of rounded knobs about the free end, and later elongate. A mouth breaks through at the distal end of the body, and finally, the base constricts itself off, closing communication with the internal food cavity of the parent, and develops a foot for independent attachment. Then the little hydra drifts away to set up in business on its own account. This is obviously an asexual process of reproduction.

The sexual process is not so often observable. The sexual organs, when present, appear as minute transparent swellings on the surface of the body; conical and situated above the middle, if spermaries; low and broadly dome shaped and situated nearer the foot, if ovaries.

If a hydra be transferred to a slide or watch glass and examined a little magnified, the two constituent layers of its body wall may readily be made out: a transparent outer ectoderm, and a darker inner endoderm. The endoderm lines the food cavity, which is merely a blind sac having only one opening, the mouth, through which food is taken in, and its indigestible residue is thrown out. The tentacles being

formed by outgrowth of both layers are hollow, each is a similar smaller blind sac opening into the major cavity. This very simple plan of structure is indicated in the accompanying diagram (fig. 60, *c*).

The body of the hydra is too large for the satisfactory study of the form and relations of its constituent cells in the living animal. The two cell layers are easily made out, and, in the slender and transparent tip of an extended tentacle,

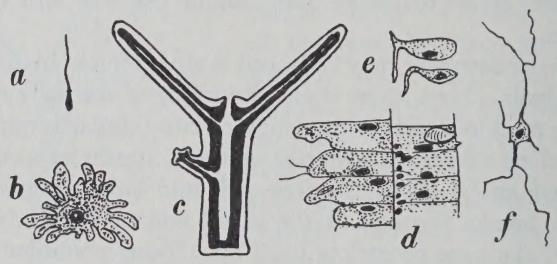



FIG. 60. Hydra. *a*, a sperm cell; *b*, an egg cell; *c*, diagram of a longitudinal section of the body, bearing a lateral bud, ectoderm white, endoderm black; *d*, a bit of the body wall showing tissue layers; *e*, dissociated cells with basal contractile processes; *f*, a rudimental nerve cell.

some large nettling cells (*nematocytes*) are readily observable. These contain transparent ovoid sacs (*nematocysts*) (fig. 61) occupying slight elevations of the ectoderm of the tentacle. Inside each nematocyst is a closely coiled stinging filament, which when discharged in contact with a water flea, paralyzes it and prevents its escape. Close beside each nematocyst is an erect minute sensory point, which when touched by the water flea, communicates the stimulus that causes the discharge of the filament.

This discharge may be caused artificially, while one is watching, if some irritating fluid, like dilute acetic acid, be run under the cover glass that confines the hydra upon a slide.

By keeping one's eye at the microscope while the acid is diffusing under the cover until it comes in contact, some of the nematocysts will be seen to be thrown out bodily, while others will throw out only their filaments, which will then hang like long flexuous transparent hairs to the side of the tentacle.

**The cellular structure** of the hydra is made out by the study of thin sections and of macerated preparations of dissociated cells. In a cross section of the body, ectoderm and endoderm stand out with diagrammatic clearness. Their constituent cells are seen to be considerably differentiated, those of the endoderm being rather larger, and variously shaped at their free internal ends, where some bear flagella, and others pseudopodia. Digestion in the hydra combines the methods of the lower animals hitherto studied, in which the food is engulfed by the protoplasm and digested within the cell, with that of the higher animals, in which the food is digested in a stomach (through the action of fluids poured out by the cells) and afterwards absorbed. Individual cells of the endoderm of the hydra digest minute diatoms, etc., after the former method; the endoderm collectively digests water fleas and the larger kinds of prey after the latter method.

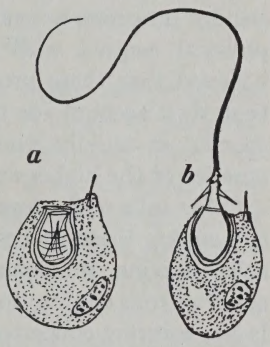



FIG. 61. Nettling cells of the hydra. *a*, charged; *b*, discharged.

**The ectoderm** is a composite layer. Larger cells that form the surface, and smaller interstitial cells fill the spaces between their bases. Some of them develop into nematocytes by a remarkable differentiation of the cytoplasm of their upper ends. It is probable that after the discharge of the nemato-

cysts, other interstitial cells act as replacement cells, growing up and producing new ones.

There is a significant development of the base of the ectoderm cells that can only be made out well if the tissues be dissociated so that the cells may be viewed singly. In such a preparation, many of the cells are seen to have long slender processes extending beneath the ectodermal layer, in physical contact with many of its cells (fig. 60, *e*). It is believed that these processes are especially contractile, and that they account for the ability of the body as a whole to shorten so rapidly when disturbed. These foreshadow the muscles of the higher animals.

Other cells of the form shown in figure 60, *f*, are also present among these processes and appear to be primitive nerve cells, serving to communicate the stimuli and to secure simultaneous contraction of all the cell processes of the whole layer, securing concerted action.

The hydra is a large and fairly well integrated body of cells, among which division of labor is very obvious. Clearly the digestion and absorption of food must fall to the endoderm cells, which alone come into contact with it. Likewise, the protection of the body and responses to stimuli from without must fall to the ectoderm cells. The function of the nettling cells is much more specialized.

**Sex cells.** — Both spermaries and ovaries develop in the ectoderm, each as a little mass of cells covered by a thin, transparent ectodermal film.

In the spermary, each included cell develops a motile sperm (fig. 60, *a*) which when mature may be seen actively swimming about in the transparent conical tip of the spermary of the living hydra.

Of the cell mass which is to be the ovary, one cell gains the ascendency and grows at the expense of the others, absorbing

their contents and storing up reserve food materials. This cell which when mature is the egg, has the singular amœboid appearance shown in figure 60, *b*. At maturity the top of the ovary bursts, making a passage for the ingress of the sperms, and, in fertilization, one of these fuses with the egg cell.

## II. The Earthworm [1]

To every one who turns the soil in flower bed or garden this animal is very familiar. It assists in tillage by perforating the soil with its burrows, and by carrying subsoil up from below in the " castings " which it strews around the mouth of its burrow, and mixes with the humus. Being nocturnal and blind, its activities may be easily observed with a lantern on a wet night, when it will be found partly extended from its burrow, reaching about over the soil from its doorway, ever ready to make a quick retreat if disturbed. If seized quickly and held still for a moment until it releases its hold on the walls of its burrow, it may then be pulled out. This is the way to get specimens for study.

**External features.** — The body of the worm is segmented i. e., it consists of a series of transverse rings or segments (*somites*). There is no head and no tail, but there are definite front and hind ends. At the former is the mouth, overhung by a muscular flap or fold, the *prostomium*, which, in absence of arms or tentacles, assists in getting food into the mouth; at the other end is the anus; and the alimentary canal extends straight through the middle of the body from from end to end.

The ventral surface of the worm is somewhat flattened, and at either side of it are two double rows of minute setæ

[1] The following outlines apply especially to the large *Lumbricus herculeus*, which, on account of its size, is a favorable form for dissection.

with their tips protruding through the skin. They are short and stiff, and not at all conspicuous — indeed, are easier felt than seen, as one may demonstrate by drawing a worm backward between the thumb and finger. It is by means of these that the worm maintains its footing in crawling, or its hold within its burrow.

The only conspicuous external feature is the broad girdle or *clitellum* that surrounds the body between the thirtieth and fortieth segments. Although inconspicuous, the openings of the ducts from the reproductive organs may be seen at the sides of the ventral surface of segments fourteen and fifteen, between the rows of setæ.

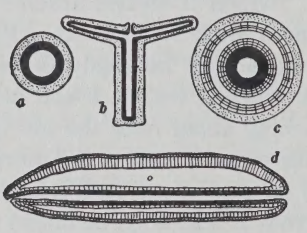



FIG. 62. Diagrams of the structure of hydra and worm. *a*, cross, and *b*, long sections of hydra; *c* and *d*, corresponding sections of the worm. The ectoderm is stippled, the endoderm solid black, and the mesoderm of the worm, cross-lined; *o*, cœlom.

**Internal features.** — The body of the hydra is tubular in plan; that of the worm is compound-tubular — a tube within a tube; the inner tube is the food tube, alimentary canal or *enteron;* the outer is the body wall; the space between is the body cavity or *cœlom* (fig. 62).

If a slit be made through the body wall of an anæsthetized worm along the mid-dorsal line, and the cut edges be drawn apart for inspection of the interior, it will at once be seen that the segmentation of the worm extends to the internal organs — that segments of the worm are delimited internally by thin transverse membranous partitions or *septa*, which divide the cœlom into a series of compartments, within which certain structures are serially repeated. At the middle of the body these structures are typically seen. The large

enteron occupies the center of the body. A slender vessel of bright red color extends along its dorsal side. This is the *dorsal vessel*, the central part of a blood vessel system. Its color is due to the contained blood, which it drives forward by evident pulsations of its walls. It is joined in every segment by small lateral paired blood vessels, some of which may be traced to the body wall and some to the walls of the enteron. If the septa be cut for a little way on one side, and the alimentary canal be pushed over to the other side, another smaller longitudinal blood vessel, the *sub-intestinal*, may be seen extended lengthwise beneath it. In this the flow of the blood is toward the rear. In the seventh to eleventh segments of the body there are large paired strongly contractile blood vessels, the *aortic arches*, extending downward each side joining the dorsal vessel to the sub-intestinal.

**Nervous system.** — On the floor of the body cavity beneath the sub-intestinal vessel lies the white nerve cord, from which slender branching nerves arise in every segment. In the foremost segment of the body this cord divides into two commissures which pass one on either side of the enteron, and reunite above it in a mass of nervous tissue that is the brain or cerebral ganglion. From the brain arise nerves that pass into the prostomium and into the walls of the enteron.

**The food tube or enteron.** — This canal is differentiated at its anterior end into a series of organs. Immediately behind the mouth is a muscular pharynx. The circular muscles of its walls contract it, and the copious radiating fibers that extend outward on every side to the body wall, expand it, making it an efficient organ for sucking the food into the mouth. Behind the pharynx, the esophagus extends as a slender passage-way leading to the thin walled and disten-

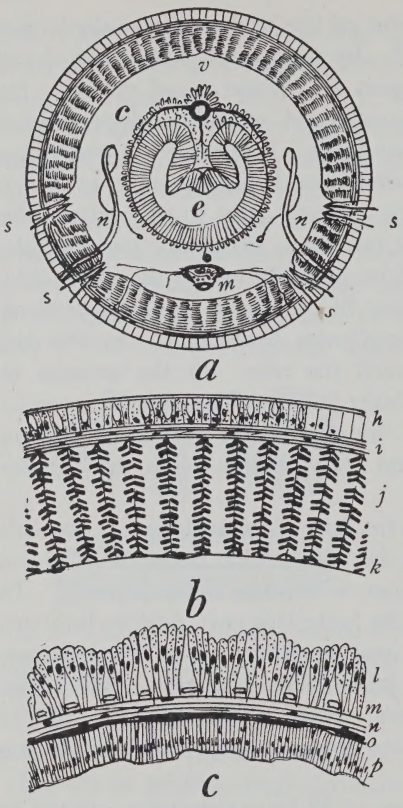



FIG. 63. Diagrams of worm structure. ***a***, cross section of the body; *e*, food tube or enteron; *c*, cœlom; *n*, *n*, nephridia; *v*, dorsal blood vessels; *m*, ventral nerve cord, with subintestinal vessel above it and subneural vessel beneath it; *s*, *s*, *s*, *s*, setæ.

***b***, cross section of the body wall, *h*, hypodermis or epidermis, with covering cuticle; *i*, circular muscle layer; *j*, longitudinal muscle layer; *k*, peritoneum.

***c***, cross section of a bit of the wall of the enteron. *l*, chloragogue cells (modified peritoneum); *m*, isolated longitudinal muscle fibers; *n*, circular muscle layer; *o*, blood spaces; *p*, digestive epithelium (endoderm).

sible crop, which lies at about the fifteenth segment and this immediately adjoins the thick-walled muscular chitin-lined gizzard, which comes nearest to a grinding organ of anything possessed by the worm.

The remaining part of the alimentary canal is undifferentiated stomach-intestine. In this the final digestion and absorption of the food occurs. If the alimentary canal be slit open and washed out (it will evert itself in a freshly killed worm by the contraction of the circular muscles of its walls) a sudden change in the color of the lining tissues will be seen at the beginning of the stomach-intestine. At this place the digestive epithelium begins.

**Nephridia.** — In the cœlom at either side of the enteron in every typical segment will be

seen a delicate whitish organ, at first appearing like a tangle of whitish threads; it is the *nephridium*, a simple excretory organ, whose principal function is the removal of nitrogen waste from the body. It is a coiled and twisted tube, which opens into the body cavity by a funnel-shaped aperture lined with cilia, and to the outside by an excessively minute pore that is situated near the lower line of setæ. The body of each nephridium lies in one segment, and the funnel aperture and short stalk-like beginning of the tube (which perforates the septum low down near the nerve cord) lies in the preceding segment.

The relations of the nephridia to the body as a whole, and to the other internal organs, the principal trunks of the circulatory system, the position of the setæ and of the principal muscle bands are indicated in the accompanying diagram of a cross section of the worm.

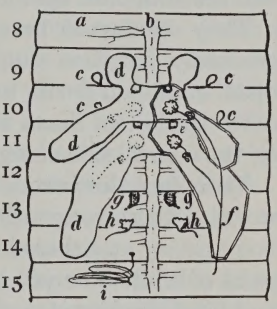



FIG. 64. Diagram of reproductive organs of the earthworm, as viewed from above, the body wall outspread, and the enteron removed. *a*, nerve branches; *b*, nerve cord; *c*, sperm receptacles, *d*, *d*, *d*, sperm vesicles; *e*, *e*, spermaries (two pairs); *f*, sperm duct; *g*, *g*, ovaries; *h*, *h*, oviducts; *i*, nephridium. Serial number of segments indicated at left.

**The muscular system** consists (1) of the broad outer sheet of circular muscles and the thick tracts of longitudinal fibers in the body wall, and (2) of circular and longitudinal fibers in the walls of the alimentary canal, and (3) of sets of slender fibers attached to the base of each seta.

**Organs of reproduction and sex cells.** — In the region of the ninth to fifteenth segments of the body, the most conspicuous parts seen are the reproductive organs (fig. 64), which are of remarkable complexity. The largest of these are the sperm vesicles, three large white paired organs in segments

ten to twelve, increasing in size posteriorly, the pair of the twelfth segment extending backward at its free end into one or two of the segments behind; these are separate only on the sides and above, being united across the median line below the enteron. They contain the spermaries, and usually a large mass of sperm cells in the later stages of development.

If one slit open a vesicle and take from it a drop of its whitish fluid contents and mount this for the microscope he will see abundant sperm cells.

They develop in berry-like clusters of ovoid cells, which gradually lengthen out into a flagellum-like tail at their distal ends, and finally break apart and swim free. They pass down the sperm ducts to the external openings already seen on the ventral side of segment fifteen.

Their first destination is the sperm receptacles of another worm. These receptacles may be seen on the floor of the body cavity at either side of the foremost sperm vesicle, two pairs of whitish or yellowish sacs, whose outlets are at front and hind margins of segment ten.

The sperms are extruded in copulation, when two worms come together in reversed position, so that the ventral surfaces are opposed to each other. With segment fifteen of one worm facing segment ten of the other, mutual exchange of sperms occurs. The sperms of each worm are received in the sperm receptacles of the other worm. This is preliminary to fertilization.

The eggs are produced in a single pair of simple ovaries that lie in the thirteenth segment, attached near the nerve cord to the septum in front. When mature they break away and lie free in the body cavity. Later they enter the funnel-shaped end of a short oviduct, that penetrates the septum at the rear of the thirteenth segment, and opens to the exterior on the ventral surface of the fourteenth segment, as before noted.

**Fertilization.** — A preliminary change in the clitellum precedes the discharge of the eggs. The glands, to which the clitellum owes its thickness, secrete a milky fluid within it that loosens it from the body. It breaks its moorings, and is gradually worked forward and finally slipped off over the front end. Its front and rear openings are elastically held close to the sides of the worm, retaining all its fluid content, into which while passing segment fourteen, the eggs are discharged, and while passing segment ten, the sperms, also, stored there previously, derived from another worm. Passing off at the front, the ends close elastically, making a cylindric capsule with pointed ends. Within this fertilization takes place — cross-fertilization, of necessity, and the eggs pass the early stages of their development in the milky fluid in which they float; it is for the young worms both cradle and food.

These capsules are left lying under leaves on damp soil, into which the little worms on emergence may enter.

Thus the worm, like the hydra and many of the other lower animals is bisexual (*hermaphroditic*). Cross-fertilization, in the hydra secured by the earlier maturing of the sperm cells than of the eggs, is in the worm secured by the complicated method just described. For the sperm cells are essentially aquatic; in the water they may reach the egg unaided, but in order to fulfill their function in terrestrial animals they require to be transported.

**Early development.** — The cellular structure of the earthworm is best understood when considered in the light of its origin. The worm, like all other organisms begins life as a single cell. In a broad sense, two processes make up its physical career: cell multiplication, and cell differentiation. The former necessarily precedes; the latter predominates during the latter stages of development, but both take place concurrently throughout life in parts of the body.

The egg (fig. 65, *e*) when fertilized is potentially a new worm. Whatever characteristics are to appear in the adult are already inherent in it. It is isolated from further parental influence. It develops of itself.

FIG. 65. Ovary and sex cells of the earthworm. *s*, sperm; *e*, egg.

There is nothing of the worm structure visible in it; we can see in it only the usual parts of a normal undifferentiated cell — a nucleus, cytoplasm, and inclusions within the cell wall. Moreover, there is nothing suggestive of a worm in the earlier of the series of remarkable changes through which it passes in development (fig. 66). It divides into two cells, the two divide into four, the four into eight, the eight into sixteen, etc., by a regular

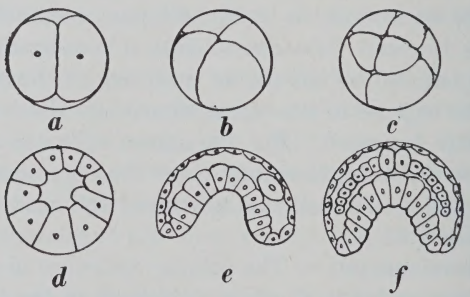



FIG. 66. Diagrams of the development of the earthworm, early *a*, *b*, *c*, 2-cell, 4-cell, and 8-cell stages, respectively; *d*, *e*, *f*, sections of later stages showing gastrulation, and the formation of the mesoderm (after Wilson).

and nearly equal division. This process is common to all animals above the protozoans, and is called *cleavage* or

*segmentation*. It results in a hollow sphere of cells (fig. 66, *d*) arranged around the now distended wall of the old egg, and called a *blastula*.

Then with the continued increase of cells by fission the wall of the blastula becomes pushed in on one side like a hollow rubber ball indented with the thumb. As the central cavity deepens the walls come closer together, and their convergent edges form a round opening, the *blastopore*. In this two-layered body we may already recognize ectoderm and endoderm, having the same general relations as in the body of the hydra. These are the primary germ layers. Here they are not obviously differentiated at first except by their position. This form of embryonic body is called a *gastrula*, and the process of invagination by which it is produced is called *gastrulation*. The cavity which corresponds to the food cavity of the hydra is called the *arch-enteron*.

A third germ layer, the mesoderm, appears in the worm before gastrulation is completed. It originates as an ingrowth of cells into the narrow segmentation cavity, as indicated in the accompanying diagrams. The diagrams of figure 67 show also how it splits into two layers (joined by rows of cells that later develop into the septa) the inner one of which (the *splanchnic layer*) becomes applied against the endoderm to form the larger part of the wall of the enteron; the other (the *somatic layer*), applied to the ectoderm, becomes much the greater part of the body wall. The cleft between these layers is the cœlom. The blastopore in the worm becomes the mouth; the breaking through of the tissues at the opposite end of the body transforms the primitive food sac into an alimentary canal — having the obvious advantage of permitting uninterrupted passage of food, and facilitating also the structural and physiological differentiation of parts along the way.

Thus at a very early stage of its development, the fundamentals of the plan of structure of the earthworm are clearly established.

**Later development.** — After the completion of the enteron, there occurs along with the rapid elongation of the body, an ingrowth of the ectoderm at both ends (but principally at the front end) which results in the restriction of the endoderm to that part already designated in the adult worm as stomach-intestine. The diagram of figure 62, *d*, indicates roughly the distribution that the three germ layers acquire.

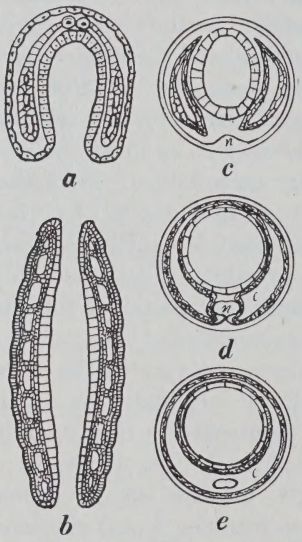



FIG. 67. Diagrams illustrating further development of the earthworm. *a* and *b*, longitudinal sections of later stages; *c*, *d* and *e*, cross sections of the body showing the splitting of the mesoderm and the formation of the ventral nerve cord. The ectoderm is white; the endoderm is cross-lined and the mesoderm is hatcheled; *n*, nerve cord.

The three are unlike in the nature and extent of the differentiation of their cells in the formation of tissues. The embryonic endoderm becomes the adult epithelium — digestive epithelium (and that only) in the worm. The ectoderm differentiates chiefly into two sorts of cells: (1) into epidermis, which remains in the original position on the surface of the body and fulfills the primitive function of protection; and (2) nerve cells, which are separated off from the ectoderm upon the ventral side as indicated in figure 67, *c*, *d*, *e*, and pass between the developing masses of mesoderm to lie within the cœlom and to develop there the nervous tissue.

It is enclosed, however, by an investment that is of mesodermal origin.

These nerve cells cease early to divide. They develop among themselves intercommunicating processes, and externally, other longer and slenderer unbranched processes which become the nerve fibers, and extend to remote parts of the body. The original cell heaps become the ganglia which collectively make up the cord, and each ganglion becomes the center for the receipt of stimuli and coördination of responses for all the parts of its segment. These cells have no other function than sensory communication between the parts of the body: the accompanying diagram (fig. 68) shows an arrangement clearly adapted to that office.

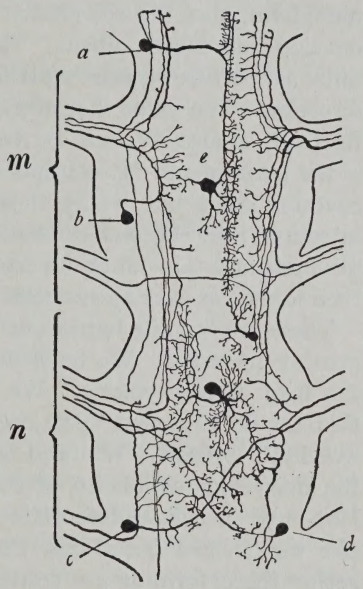



FIG. 68. Diagram of distribution of nerve cells and fibers in the portion of the ventral nerve cord of the worm lying in two segments (*m* and *n*); cell *a* sends fibers forward and backward within the cord; *e* and *f*, are centrally located multipolar cells; all the others are unipolar; *b*, sends a fiber out on its own side; *c* and *d*, each sends a fiber out through a nerve on the opposite side of the cord (after Retzius).

Mesoderm we did not find in the hydra, but in the worm it gives rise to the greater part of the adult body. The germ cells remain in the mesoderm unspecialized. The *leucocytes*, (or white "corpuscles") of the blood, also, retain a singularly primitive amœboid form. They move about freely in the

fluids of the cœlom, where they serve the useful function of feeding on bacteria and other foreign substances and carrying them out through the tissues of the body wall to the surface and thus, removing them. The nephridia develop from the mesoderm, also, but the greater part of the mesodermal cells develop into muscle fibers. They elongate greatly, and acquire a structure especially fitting them for contracting in one direction. The tissue that overspreads the walls of the cœlom (formed, as already seen, by the splitting of the mesoderm) is the peritoneum. It consists for the most part of thin flat covering cells, but where these cells overlie the stomach-intestine they become distended with waste assimilation products and take on an inverted flask-shaped form, and are then known as *chloragogue* cells.

These are but the barest outlines of the principal developmental processes. We have not time to enter farther into the field of embryology. We have gone far enough to see that the development of an organism from an egg is a truly wonderful process. We need but go back again and look at the marvelous simplicity of the egg to be convinced of it. Not only do cells differentiate, but cell groups act together like well drilled battalions, cleaving apart here, fusing together there, forming protective coverings or communicating channels, apparently creating out of nothing, a whole set of nutritive and reproductive organs, all in orderly and progressive sequence, producing in the end that orderly cell aggregate which we know as an earthworm.

**Summary.** — Although the forces involved are beyond our ken, the grosser processes are evident, and may be summarized as follows:

1. In respect to development, the general phenomena are: cell multiplication and cell differentiation.

2. The principal changes of form and relations are: seg-

mentation, gastrulation, formation of the mesoderm, splitting of the mesoderm, formation of the food tube, origin of the nervous system from the ectoderm, origin of the nephridia and reproductive organs from the mesoderm, ingrowth of the ectoderm at both ends. These are the A, B, C's of embryology.

3. The derivation of the principal tissues from the three germ layers is: From the ectoderm:

epidermis and setæ
lining of fore and hind gut
the whole nervous system

From the endoderm: the alimentary epithelium

From the mesoderm:

muscle and connective tissue
blood and blood vessels
peritoneum and chloragogue
nephridia
reproductive organs

Let us now try to get a bird's eye view of the life process in the worm. Both the substance for the building of its body and the energy for its operation are contained in the food. This consists of organic matter (proteins and carbohydrates) and salt solutions mixed with a remarkable large proportion of indigestible materials (sand, clay, etc.), that come with the earth and rubbish that the worm swallows: also, of the free oxygen absorbed through the skin from the air. The solid food is pulled to pieces by the prostomium, sucked in by the pharynx, passed down the slender esophagus to a temporary storage in the crop and triturated by the gizzard (all purely mechanical treatment), perhaps mixed with some secretions along the way, and then passed on into the stomach-intestine. Here digestion and absorption take place. These are the work of the epithelial cells. But these cells are

remote from many parts of the body, and all parts have to be fed, therefore, the food must be transported. Circulatory apparatus exists because the slow process of diffusion is inadequate to the needs of so large and active an organism. Into the blood percolating through the intercellular spaces about the bases of the epithelial cells the dissolved food diffuses, and passes upward through the dorso-intestinal vessels to enter the great dorsal trunk for distribution all over the body to every living cell.

For nutrition is at bottom the work of the cell. One set of cells may attend to the digesting and another to the circulating of the digested material, but every cell must eat for itself. No amount of division of labor can relieve any cell of the necessity of assimilating and excreting. For these metabolic processes oxygen is also necessary, and this the worm gets after a very primitive fashion — by direct absorption through the skin. To facilitate this the skin is kept moistened with the watery mucus poured out upon it by numerous secreting cells in the epidermis (fig. 63, *b*, *h*).

The red color of the blood is due to the presence in it of hæmoglobin, a substance that is an excellent agent for the transport of oxygen. It combines loosely with free oxygen, taking it up readily where there is a copious supply, as at the skin, and giving it up easily, where affinities for it are stronger, as in the active and deoxydized tissues. The blood is, therefore, the carrier of both food and oxygen to every cell. It carries the former outward from the stomach wall, the latter inward from the skin.

Income and outgo are not essentially different for any cell in the worm's body from the same process in the protozoan cell as outlined on p. 37. More food passes through the epithelial cell and more oxygen through the epidermal cell than through the others, as more stores pass through the

seaport towns of an importing country than through the interior ones; but the part reserved by each for its own use is used by all in much the same way. The output of matter is, therefore, as in the protozoan, mainly water, carbonic acid gas and simple nitrogen compounds.

These waste products must be gotten rid of, and while the cells of the surfaces of the body may excrete them directly to the outside, those of the interior need the circulatory system to carry off their waste. The dispersal of the carbon dioxide and water is as general over the surface of the body as the intake of oxygen. With these, doubtless, goes a part of the nitrogen waste also; but the nephridia are special agents for disposal of the nitrogen waste. To these the blood goes, laden with the products of proteid dissimilation, and in them these substances are removed and passed to the exterior.

Another and very peculiar mode of waste disposal occurs in the worm. The cells of the peritoneum, where they cover the parts chiefly concerned with the elaboration of the food, (stomach-intestine and larger blood vessels leading forward therefrom) instead of remaining thin and flat become elevated into high pear-shaped sac-like bodies attached by their slender pointed ends, and filled more or less completely with yellowish-green granules of a substance called *chloragogue*. It is not quite certain what is the nature of these granules but they are believed to be waste nitrogenous products, and it is certain that they accumulate in the cells until the cells are distended and burst. Then they fall free into the body cavity. A drop of the body fluid taken at random with a pipette from an adult worm is certain to contain numbers of these isolated greenish-yellow granules. They filter posteriorly through the holes in the septa, and finally accumulate in little brownish lumps, intermixed with dislodged

setæ, in a few of the hindmost segments. There they are consumed by commensal nematodes. The blood always contains, besides these granules and leucocytes already mentioned, great numbers of bacteria, which the latter feed upon, and occasional parasites.

## III. The Salamander

The spotted salamander (*Ambystoma tigrinum*) is a vertebrate, of rather primitive structure. It will serve very well to illustrate that type of animal organization that is found in our own bodies.

It is nocturnal and very secretive in its habits, being often seen in cellars and basements when doors are left open, although occasionally dug up in moist garden soil, or found by overturning logs, etc., in the woods. It is of elongate form

Fig. 69. The Spotted Salamander, Ambystoma.

(fig. 69), with a moist scaleless skin, short legs, that are used more for propulsion than for support, and with a stout laterally flattened tail. It is of greenish-black color, ornamented with irregular and variable yellow spots. Its appearance excites the fears of some superstitious and ignorant people, but it is quite harmless and inoffensive.

Specimens are easiest obtained by taking advantage of their mishaps. They migrate from the fields and woods back toward their native ponds in late fall and early spring, and fall into any hole that lies in their path. In crawling

about the foundations of buildings they get into basements; the walled semicircular pits surrounding old-fashioned basement windows capture many of them. They will fall into any hole that offers, but can crawl out again if the sides be not rather smooth and vertical. Any low barrier interposed between a pond and adjacent hills, such as a long curbing, will detain them temporarily, where they can be picked up with the aid of a lantern at night. They are easily kept in any cool moist place and need no food in winter.

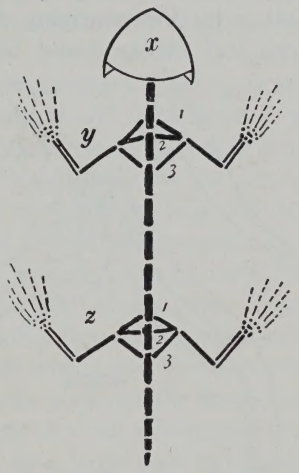



FIG. 70. Diagram of a vertebrate skeleton. *x*, skull; *y*, fore limb; *z*, hind limb; *1*, *2*, *3*, in front, clavicle, coracoid, and scapula, composing the shoulder girdle; *1*, *2*, *3*, behind, ilium, ischium and pubis, composing the hip girdle.

If a living salamander be examined some of the characters of backboned animals will be readily apparent. First of all, the axis of support (fig. 70, *spinal column* composed of *vertebræ*) is located in the body wall upon the dorsal side and in consequence the thick dorsal wall of the body stands in marked contrast with the thin and soft ventral wall. This axis is extended posteriorly into the tail, and expanded anteriorly to form part of the skull, which is the skeleton of the head, and which may readily be felt with the fingers through the soft skin. Two pairs of appendages are quite characteristic of vertebrates.

The close correspondence between fore and hind limb will be obvious even in the living specimen. Both have a supporting girdle of bone embedded in the side walls of the body

and more or less firmly attached to the axial skeleton. Upper arm, fore arm, wrist and hand, in the fore limb, correspond to thigh, shank, ankle and foot, respectively, of the hind limb. The divisions between these joints may readily be determined by flexing them between the fingers. Were not this internal jointed skeleton, with its numerous bones united by strong ligaments and moved upon each other by the overlying muscles so familiar to us, its mechanical fitness would be most impressive.

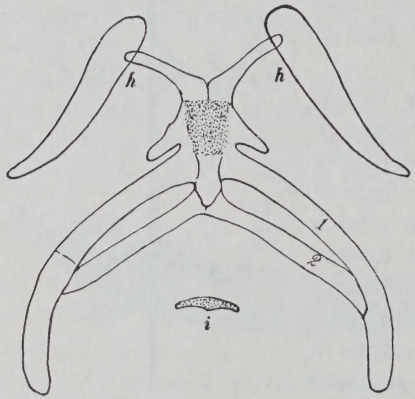



FIG. 71. The branchial skeleton from the throat of the salamander. *h*, the hyoid arch; *1* and *2*, lateral arms of the first and second branchial arches; *i*, isolated basal piece corresponding to the missing branchial arches.

Another small part of the skeleton, located in the ventral wall in the region of the throat, is the hyoid apparatus (fig. 71). This is mainly cartilaginous, only the part that is stippled in the figure being bony. The anterior fork supports the base of the tongue; the postero-lateral arms curve upward about the sides of the neck. These may be felt with the fingers beneath the skin of the throat, or moved about under the skin by moving the tongue with a forceps. This part of the skeleton, though small and weak, is of great historical importance. These paired cartilaginous arches are landmarks of vertebrate history: to their consideration we shall have occasion to return later.

The eyes of the salamander are prominent and shining

and they both wink at once at long intervals. If one of them be touched gently, it will be withdrawn completely into its orbital cavity; thus it gets out of harm's way.

Once in a while the salamander may be seen to gulp down a mouthful of air. It does not inhale; to get air down it has to swallow. The air-swallowing process will often be most clearly seen after the specimen has been handled and put down again. On the under side of the neck the pulse beat may be seen.

On the body there is a mid-dorsal groove extending from the rear of the head to the base of the tail, and there is a series of *costal* grooves between fore and hind legs traversing the sides of the body vertically. These latter are the external evidence of that segmentation of the body that will be found later in the vertebræ, spinal nerves and ganglia, and muscle segments. A number of similar grooves may be seen on the sides of the tail, especially at its base. The surface of the skin is covered with the very minute openings of pores from the large skin glands within it. These pores are visible with a lens. These glands pour out the secretion which keeps the skin moist and enables the salamander to get its oxygen, as the worm does, in a large part by direct absorption. It depends far less on its lungs for air than do the higher vertebrates. Some vestiges of its early aquatic life are preserved in the rudimentary webbing between the bases of the toes, and in the flattening of the tail, which is still put through superfluous sculling motions when the salamander tries to run on land.

At the tip of the snout a pair of small nostrils will be seen, each with a blackish valve-like flap attached to its hind margin within, and if the mouth be held open widely, the inner openings from these nostrils may be seen on its roof at the rear of the palate. On the floor of the mouth lies a fleshy

tongue, attached along its middle line, its edges lying free; at the rear of the mouth, the pharynx, with its walls converging to the esophagus, penetrated by abundant minute blood vessels, which give to it something of the character of a respiratory organ. In the lungless salamanders this organ is more abundantly supplied with blood vessels.

On the floor of the pharynx is the glottis, the gateway to the lungs, a narrow longitudinal slit with closely appressed cartilaginous lips. Very minute and numerous teeth may be found on the edges of the jaw by scraping it with a finger nail or with a needle, and two patches of palatine teeth may be found farther back in the roof of the mouth.

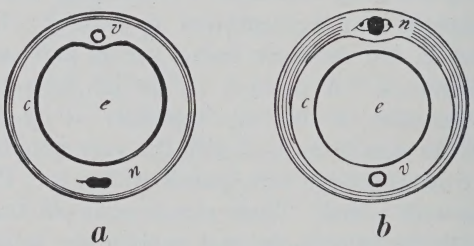



FIG. 72. Diagrams illustrating the plan of body in worm (*a*) and in salamander (*b*) in cross section; *e*, enteron; *c*, cœlom; *n*, central nervous apparatus; *v*, central circulatory apparatus.

**Internal features.** — Upon looking inside the body of the salamander it is at once apparent that the main general features of structure that were found to characterize the earthworm, are repeated here. There is a compound-tubular body, a tube within a tube, and a cœlom or body cavity between; the inner tube is the alimentary canal and the outer one is the body wall as before, but the alimentary canal differs in two important particulars; it is not straight, but greatly coiled and twisted; and it is not simple,

but bears conspicuous appendages. And the body wall differs conspicuously in that it bears a differentiated head, and is extended laterally into limbs and backward into a tail.

On comparing the internal organs there are strong contrasts. The central part of the circulatory system is not a long pulsating tube lying on the dorsal side, but a heart, lying upon the ventral side. The central part of the nervous system does not lie within the cœlom on the ventral side, but in the body wall upon the dorsal side. The nephridia are not scattered segmentally in single pairs the

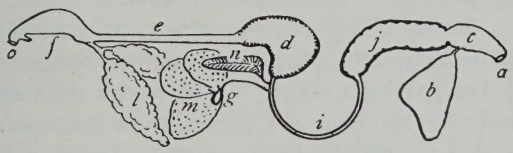



FIG. 73. Diagram of the enteron of the salamander, with its principal appendages. *o*, mouth; *f*, pharynx; *e*, esophagus; *d*, stomach; *i*, small intestine; *j*, large intestine; *c*, cloaca; *a*, anus; *b*, urinary bladder; *g*, gall bladder on *m*, liver; *n*, pancreas; *l*, lung.

whole length of the body, but are aggregated into special paired organs, the kidneys, and in the salamander there are special respiratory organs, the lungs, and special supporting structures, the bones.

The food tube, alimentary canal, or *enteron*, is differentiated into parts the anterior of which bear the same names as parts of like function in the earthworm: mouth, pharynx and esophagus, and these are succeeded by stomach, small intestine, large intestine and cloaca. All these, together with the appendages, are indicated in the accompanying diagram (fig. 73).

The stomach has become a sharply delimited organ for

the reception of food, capacious, distensible, suited to the exigencies of irregular food supply. Its thick muscular walls are filled with small gastric glands, whose secretion initiates digestion. The churning movements of the walls aid in the comminution of the food and in the mixing of it with the gastric secretion. At the outlet of the stomach is a guarded passageway called the *pylorus*, through which the food passes, when reduced to a more or less fluid condition.

The small intestine is a narrow passageway (greatly abbreviated in the diagram), well adapted to the slow passage of the food, to the completion of its digestion, and to the extraction from it of assimilable materials. It is long and tortuous. Its walls are covered internally with folds and processes (*villi*) which greatly increase the surface in contact with the passing stream. These secure the better mixing of food with the digestive secretions of the liver and the pancreas, and the completer absorption of it after digestion.

**The principal appendages of the enteron.** — The lung is here a new feature. As a respiratory sac appended to the alimentary canal, it is peculiar to vertebrates. Among terrestrial animals, most vertebrates are giants, for whom direct absorption of oxygen through the skin would be quite inadequate. Herein is seen the advantage of the lung, which maintains inside the body extensive surfaces that are thin-skinned and always moist.

The liver is the largest gland in the body, a lobed organ of mottled brownish color, its pointed left lobe partially covering the stomach (in the resupinated position in which the salamander is opened). Its secretion is collected in a bluish-green sac — the gall cyst, which the right lobe overlies. The cyst is connected by a slender bile duct with the small intestine near the stomach. Compression upon the gall cyst will usually demonstrate that the bile duct opens at this

point, by driving the greenish bile down its length, making the duct visible.

The pancreas is an elongated, thin, flat, fatty-looking organ, that lies in the loop formed by the junction of the stomach and small intestine and is covered by the liver except at its posterior end where it touches the intestine.

The urinary bladder is the hindmost appendage of the alimentary canal. It is a thin, crumpled sac that lies upon the ventral surface of the large intestine, and opens into the cloaca.

The thin sheet of membrane in which these digestive organs are slung from the dorsal side of the body wall and through which pass numerous branching incoming and outgoing blood vessels, is the *mesentery*. The elongate, oval, reddish body suspended in the mesentery behind the stomach is the spleen.

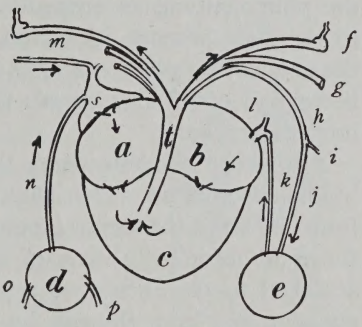



FIG. 74. Diagram of the Amphibian heart, and principal blood vessels. *a*, right auricle; *b*, left auricle; *c*, ventricle; *t*, arterial trunk; *e*, lung; *d*, liver; *f*, carotid arch; *g*, aortic arch; *h*, pulmo-cutaneous arch, with *i*, its cutaneous, and *j*, its pulmonary branch; *k*, pulmonary vein, with the base of the corresponding vein from the missing lung shown at *l*; *m*, the right precaval vein; *n*, postcava; *s*, venous sinus; *o*, anterior abdominal vein and *p*, portal vein.

The lungs are the foremost appendages of the alimentary canal. They spring from the ventral side of the pharynx at the glottis, whose location has already been noted, by a slender, hollow, stalk-like trachea, which divides into two bronchial tubes, joining the right and left lungs. By passing a pointed glass tube into the glottis and inflating the lungs, their size, their constituent air cells and the communicating blood vessels in their wall may be clearly seen.

**The circulatory system** has for its central organ a heart of three chambers, two auricles and a ventricle (fig. 74). The ventricle has thick muscular walls, and is the chief propelling agent of the blood current. It drives the blood forward through the arterial trunk, and outward through the arches, as indicated by the arrows in the accompanying diagram. The outward current is called the arterial, the inward, the venous circulation.

The carotid arch carries blood anteriorly to the head, the pulmo-cutaneous inwardly to the lungs and externally to the skin (whence its name), and the aortic arch carries the greatest supply posteriorly and to peripheral parts of the body, and distributes vessels through the mesentery to the internal organs.

The return currents reach the heart separately, entering by the two auricles. That entering the left auricle is returned from the lungs through the pulmonary veins. That entering the right auricle (by way of the venous sinus, a vestibule attached to the auricle) is returned from the front by the precava, and from the rear by the postcava. The postcava is the largest blood vessel coming from the rear. Into the liver the blood returns by two main channels, an anterior abdominal vein that traverses the mid-ventral line of the body wall and jumps across the short intervening space of the cœlom to enter the liver on its ventral side, and a portal vein that comes from the stomach and succeeding portions of the alimentary canal.

**The special organs of excretion** in the salamander are the *kidneys*, a pair of chocolate-colored bodies lying closely applied to the dorsal wall in the posterior end of the body cavity, broader and thicker behind, and tapering to a slender point in front. From their postero-external angles a pair of very short ducts connects with the cloaca, entering just

opposite the mouth of the urinary bladder, into which the urine passes for temporary storage. A large vein enters each kidney from the rear, breaks up into fine branchlets, and is reformed on the opposite internal side, where, by confluence of emerging branchlets, the postcava is formed.

All these organs perform functions connected with nutrition (in the broad sense) as in our own bodies — functions about which we have learned in our courses in physiology.

**The reproductive organs** lie in the midst of the body cavity, a single pair just ventral to the pointed anterior ends of the kidneys, and they bear usually a considerable development of fat in the form of yellowish finger-like processes (fig. 75). The salamander being unisexual, they are spermaries (*testes*) in the male and ovaries in the female.

The spermaries are oval yellowish bodies, which discharge their sperms through a number of fine ducts that penetrate the substance of the kidney and emerge on the opposite side to join the ureter, and thence reach the cloaca.

The ovaries are large, membranous, crumpled organs in whose walls the eggs may be seen developing, opaque and white at first, acquiring blackish pigment as they increase

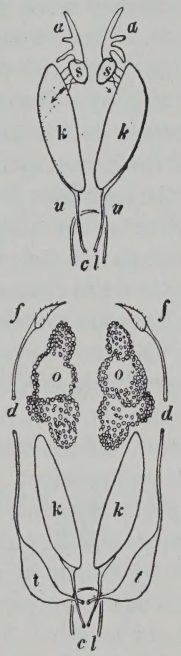



FIG. 75. Diagram of the relations of renal and reproductive organs in amphibians, male above, female below. *k*, *k*, kidneys; *u*, *u*, ureters; *cl*, cloaca; *s*, *s*, spermaries (testes). Arrows indicate the course of the sperm ducts through the kidneys to join the ureter; *a*, *a*, fat bodies; *o*, *o*, ovaries; *d*, *d*, oviducts (convolutions omitted); *f*, *f*, their funnel-shaped openings into the cœlom; *t*, *t*, the dilatation (uterus) at the lower end of each.

in size, studding the transparent membrane. The eggs are shed from the ovaries into the body cavity and the ducts by which they reach the exterior are not connected to the ovaries at all. The oviducts are long sinuous tubules extending the whole length of the body cavity near the mid-dorsal line, opening by a V-shaped slit at the anterior end that is situated between the œsophagus and the shoulder. Into this the eggs find their way, aided by the lashing of the cilia along the way. As the eggs pass down the tube a gelatinous secretion is added to them as an outer coating. They find temporary storage in a sacculation (*uterus*) at the lower end of the duct just before it enters the cloaca.

**Nervous system.** — As already noted, the central part of the nervous system in the salamander, as in vertebrates generally, is lodged in the body wall upon the dorsal side. It consists of a hollow, but thick-walled tube of nervous matter, differentiated into two principal parts: a considerable enlargement, the brain, is lodged in the cranial cavity of the skull, and a long spinal cord occupies the channel formed by the annular vertebræ. The branches it bears, and by which it maintains communication with peripheral parts of the body are paired nerves, which it gives off throughout its length. Those nerves issuing through openings in the base of the cranial cavity of the skull are called *cranial* nerves, and those issuing from the interspaces between the vertebræ are called *spinal* nerves.

The nervous apparatus of the body is composed of nerve cells and their processes. Where the bodies of the cells predominate, as in the center of the cord and in the surface layer of the fore part of the brain, they give the nervous tissue a pale grayish cast; and where the fibres predominate, the tissue appears white (the so-called " gray matter " and " white matter " of the nerve centers). We have seen a

very simple sort of differentiation of nerve cells with processes in the hydra (fig. 60, *f*). And in the earthworm (fig. 68) we have found them very highly differentiated. But in the vertebrates the processes from nerve cells are often very much longer and the interrelations between them often much more complex. Each spinal nerve consists of a bundle of these long processes or fibers, inclosed in a common sheath.

Spinal nerves arise in pairs between the vertebræ, as already noted, each by two roots (which are also bundles of fibers), and out upon the dorsal root, just before its confluence with the ventral to form the completed nerve, there occurs a little isolated cluster of nerve cells: that is, a *ganglion*. There are other nerve cells in the organs of special sense, and at the termini of sensory nerves all over the surface of the body. The apparent branching of the nerves is due to the division of the bundle of fibers into lesser bundles, and finally into single fibers that take different courses to their appropriate endings. The fibers themselves are continuous, and extend from cells in the cord or in ganglia, to other ganglia or to peripheral parts of the body. They are individual lines of nervous communication; they separate as do telegraph lines in passing outward from the commercial centers to the remoter districts.

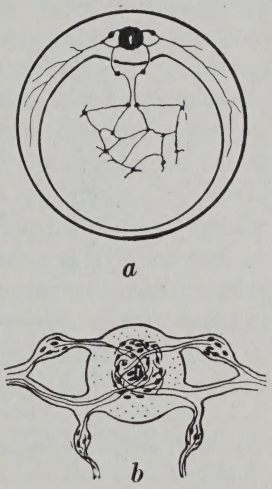



FIG. 76. Diagram illustrating the relation of the neural tube to the ganglia. *a*, is a cross section of the body showing the sympathetic ganglia in the cœlom; *b*, is a cross section of the cord and adjacent ganglia; showing roughly the location of the groups of nerve cells.

Within the cœlom of vertebrates there are other ganglia, in part arranged in pairs segmentally and connected with

the ventral roots of the spinal nerves, as shown in figure 76, and in part variously disposed in the walls of the internal organs of the cœlom, whose functions they control and coordinate. These are connected with each other by nerve fibers. They together constitute the so-called *sympathetic* or *autonomic system*. The fundamental nutritive processes of the body, that are performed involuntarily, and that are es-

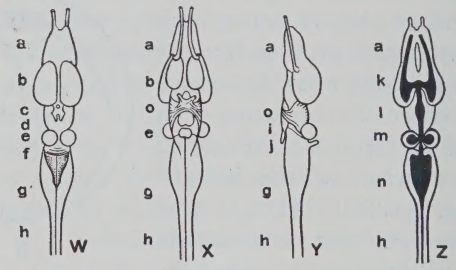



FIG. 77. Diagrams of the brain of the salamander. *w*, dorsal view; *x*, ventral view; *y*, lateral view and *z*, diagram of the continuous internal cavity in dorsal or ventral view; *a*, olfactory lobe; *b*, cerebral hemispheres; *c*, pineal body; *d*, thalamencephalon; *e*, optic lobes; *f*, cerebellum; *g*, medulla, *h*, spinal cord; *i*, infundibulum; *j*, hypophysis; *k*, lateral ventricles; *l*, third ventricle; *m*, optic ventricles; *n*, fourth ventricle; *o*, optic chiasma, the crossing of the optic nerves.

sential to keep life going, are unconsciously controlled through this system. Practically all the involuntary muscles of the body, those of the skin, as well as those of the viscera, are controlled through nerve fibers that take their origin from the cells of these ganglia.

There is another, more direct line of communication between the organs of the cœlom and the brain. One pair of cranial nerves (called the *vagi;* sing. *vagus*) which descends through the neck into the cœlom, sends branches also to the lungs, the heart, the stomach and part of the intestine.

The movements of the involuntary muscles are comparatively simple and uniform, but those of the voluntary muscles of the body wall and limbs are infinitely varied and complex, and are ever effected in new combinations. Hence there is a correspondingly large proportion of the regulative cells of the body, the nerve cells, located in the neural tube. The most significant new feature of cell grouping found among vertebrates is the aggregation of nerve cells at the forward end of the neural tube to form the brain. The cord widens on entering the skull into the medulla. On its dorsal side a thin roofed V-shaped slit, called the *fourth ventricle*, exposes the central cavity that extends in fact throughout. A transverse ridge of nervous tissue at the front of the fourth ventricle upon the dorsal side is the *cerebellum*. A pair of rounded swellings just in front of the cerebellum are the *optic lobes*. The pair of large oblong lobes at the front are the *cerebral hemispheres*. These and other parts externally visible may be located by reference to figure 77. Their relations will be considered when their development is studied.

## Development

The way of access to intelligent comprehension of the cellular structure of the salamander lies through the study of its development.

The salamander begins life as a single cell, the result of fusion of egg and sperm. It is a very large cell, because distended with yolk and enveloped by a thick gelatinous envelope; but the protoplasmic part, the living part of it, is very small. The protoplasm is not equally distributed through the egg, but is more abundant on the upper pigmented side. Therefore, the division planes in cleavage start on the upper side, and division is somewhat retarded below by the impeding yolk mass.

The cell divides into two cells along a meridional plane and the two divide into four by another meridional plane at right angles to the first; then the four divide into eight by a plane parallel to the equator of the sphere, at right angles to both former planes, not at the equator, but a little nearer the darker upper pole, where it divides the protoplasm more

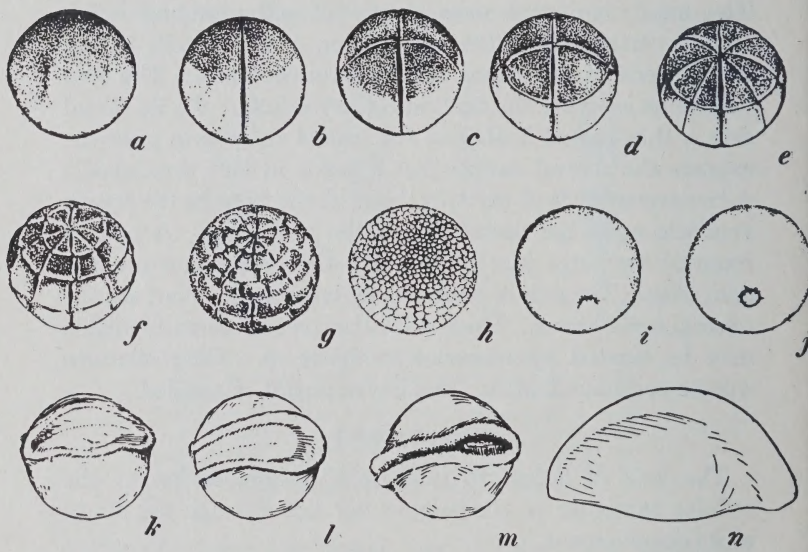



FIG. 78. Early development of salamander eggs. *a* to *h*, 1-, 2-, 4-, 8-, 16-, 32-cell and later segmentation or cleavage stages; *i*, *j*, gastrulation stages; *i*, shows the crescentic blastopore and *j*, the fully formed yolk plug; *k* to *n*, formation of the neural tube.

equally, the yolk very unequally. Successive meridional planes, and planes parallel to the equator mark the following divisions into 16-cell, 32-cell, etc., stages which, however, are not traceable farther because of the retardation of division on the lower side, and because of the planes getting ajog at the joints. The result is clearly a blastula, as seen before in

the earthworm — a hollow sphere of small cells. The slipping inward from the surface of some of its cells results in its being more than one layer in thickness over part of the upper side, and the retardation of division owing to excess of yolk on the lower side throws the segmentation cavity above the middle of the sphere. All these facts are indicated in the accompanying figures.

Then gastrulation takes place in a manner that is yet more aberrant. An ingrowth from the outer wall gives rise to endoderm surrounding an archenteron as before; but the ingrowth, impeded by yolk does not result in a widely open blastopore, but, instead, a narrow crescentic slit, the edges of the blastopore being pressed together as shown in figure 78, *i*. Then the edges of the crescent extend downward until they meet below a little circular patch of protruding yolk, the yolk plug. Except upon the upper side, where lies the direct entrance to the archenteron, they border only a shallow circular groove upon the surface of the yolk. If one conceive of his own head as the sphere of the gastrula salamander, his closed mouth the blastopore, and the corners of his mouth pulled down until they join beneath his chin, he will get a clear conception of the relation of these parts. Figure 80 shows in longitudinal sections the formation of the gastrula, and the formation and subsequent withdrawal from the surface of the yolk plug. The segmentation cavity is reduced in size as the endodermal sac increases in depth.

Then the mesoderm appears in the space between ectoderm and endoderm at the blastopore on the upper side, and spreads outward and downward in a thin sheet of tissue, and begins to split to form a cœlom.

Up to this point in development it will be observed that nothing has appeared to suggest a vertebrate animal. In the one-celled stage the embryo is more like a protozoan in

structural type; in the blastula stage it has the hollow spherical form of volvox; in the gastrula stage it is more like hydra in plan. As soon as it has acquired a compound tubular

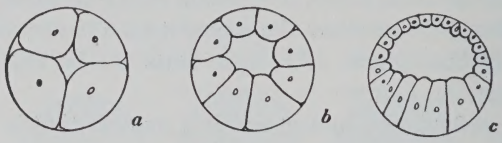



FIG. 79. Sections of salamander eggs in a meridional plane, 8-cell, 32-cell and later segmentation stages.

body through the development and splitting of a mesodermal layer, it is more like a worm, and not until the appearance of a central nervous axis upon the dorsal side is there a single structure present that can be pointed out as distinctively characteristic of a backboned animal. Thus the series of embryonic forms assumed by the salamander in its development shows a rough correspondence to the series of adult forms we have been studying.

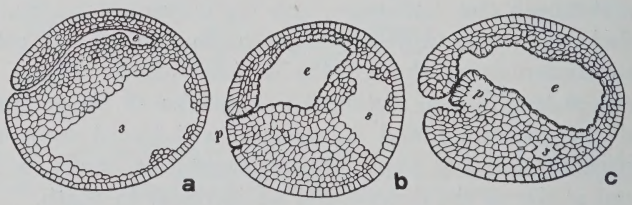



FIG. 80. Sections of salamander eggs, showing the internal changes during gastrulation. *a*, *b*, and *c*, are successive stages; *e*, archenteron; *p*, yolk plug; *s*, segmentation cavity.

**Vertebrate characters.** — Several distinctively vertebrate characters appear now in different parts of the body almost simultaneously. The first to appear externally is the nervous axis upon the dorsal side, and this and the gill slits and the notochord are especially worthy of our consideration.

Beside the blastopore an elevation appears which rises in two parallel ridges called the neural folds. These folds at their outgrowing ends are confluent in a loop which marks the head end of the salamander. These folds grow rapidly, and by their increase in length project from the surface of the egg at both ends, spoiling its spherical symmetry. The withdrawal of the yolk plug is accompanied by the outpushing of the tail beyond the end of the neural folds. The folds come together, as indicated in the accompanying figures, the wider anterior end becoming the brain, the remainder, the spinal cord. This then sinks into the interior as indicated in the cross-section diagrams of figure 81.

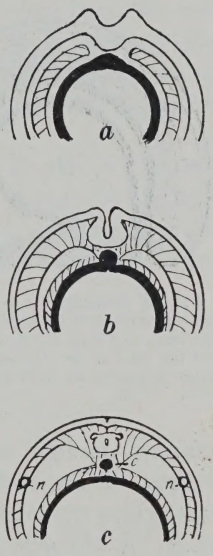



FIG. 81. Diagram of three stages in the formation of neural tube, notocord and cœlom. The ectoderm is white, the endoderm is solid black and the mesoderm is crosslined; *c*, notocord; *n*, *n*, pronephric ducts.

Meanwhile the archenteron is elongating in a parallel direction, and a fold from its dorsal wall is cutting off the notochord — the most ancient supporting structure of vertebrates — a larval organ in most of them at the present day. The archenteron is converted into an alimentary canal by a process somewhat differing from that followed in the worm; it is destined to occupy a reversed position; the blastopore becomes the anus, and the mouth is formed at the opposite end by an ingrowth from the ectoderm that meets the front end of the archenteron and fuses and then opens a passage through. The anterior end of the archenteron becomes dorsally flattened and laterally expanded into a pharynx, from whose

walls sacculations of endoderm grow outward to meet the ectoderm, and then cleave apart on vertical lines, opening gill clefts on the side of the neck. The pillars of tissue left standing between these clefts become the gill arches. By these simple processes, are laid down the main lines of vertebrate structure.

FIG. 82. Diagram of a longitudinal section of a young embryo. *n*, neural tube; *e*, enteron, the black spur from the upper side represents the free part of the notocord. The ventral outgrowth from the front end will form the liver.

**Appendages of the enteron.** — The liver arises very early (fig. 82) as a wide sacculation of the archenteron near its anterior end on the ventral side. This outgrowth becomes repeatedly branched, and the resulting glandular blind tubules becomes convoluted, the basal connection remains as a slender connecting tube, the bile duct, and the distal portion, acquiring through mesodermal additions a system of blood vessels, becomes differentiated into the lobes of the liver. A dilatation on the bile duct becomes the gall cyst (fig. 73). The pancreas arises later but by a simpler and somewhat parallel development arrives at its adult estate, when it consists of a mass of glandular-walled communicating tubes, which secrete the most important single digestive fluid of the body. The urinary bladder arises as a similar but simpler sacculation at the posterior end.

FIG. 83. A young salamander larva, showing gills slit (*s*). *b*. blastopore; *1*, *2*, *3*, fore-, mid- and hind-brain, respectively.

**Development of the neural tube.** — We have already seen that the central nervous axis develops into a tube by the closure together of two folds about a neural groove, and that the tube thus formed then sinks into the body wall. The diagrams of figure 81 show how it is overgrown, first by the ectoderm and later by mesoderm, and removed from the surface. The original neural groove thus closed becomes the central canal of the spinal cord. It is lined with a little bit of the epidermal layer of the ectoderm, carried in from the surface.

A small ridge of nerve cells that arises each side of the tube dorsally (fig. 81, *c*) becomes divided with growth into pieces corresponding in pairs to the body segments; and when later, nerves grow out as processes from the cells, these pieces be-

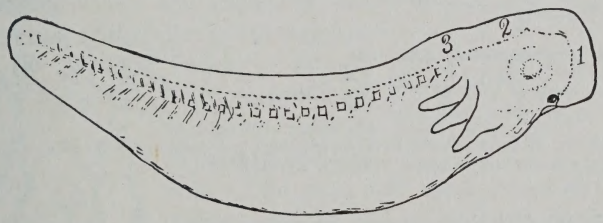



FIG. 84. Older salamander larva, showing gills, *1*, *2*, *3*, fore-, mid- and hind-brain.

come located upon the dorsal roots of the spinal nerves and become the ganglia (fig. 76) hitherto noticed.

Quite early in its development the enlarged front end of the neural tube becomes feebly marked off into three successive tracts, which correspond to the fore-brain, mid-brain and hind-brain of the adult salamander (fig. 84). Then the fore-brain becomes bilobed by a dilatation on either side of the median plane, and by growth of the two lobes forward and two extensions of the expanding canal into them, the

hollow cerebral hemispheres are formed; the olfactory lobes grow forward from beneath their anterior ends. At the rear of the hemispheres on the mid-dorsal line a small process grows upward to become the pineal body — a vestigial structure, corresponding to the nervous apparatus of a median eye, that is functional in some lizards. A hollow downgrowth on the midventral line develops the infundibulum. This connects with the pituitary body, developed in the roof of the mouth. See fig. 77 on page 126.

Paired upgrowths from the lateral wall of the mid-brain become the optic lobes of the brain. The central cavity extends into each of these, the expansions of it within the

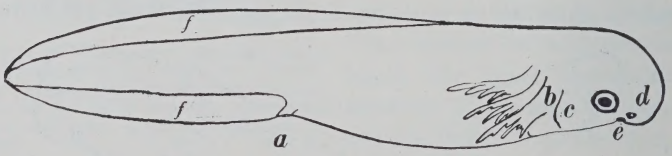



FIG. 85. Older salamander larva, showing further development of the gills. *a*, anus; *b*, gills; *c*, opercular fold; *d*, nostril; *e*, mouth; *f*, *f*, caudal fin.

optic lobes being known as *optic ventricles*. An axial dilatation of the central canal (fig. 77, *z*) is known as the third *ventricle*. From the front end of the hind-brain the cerebellum arises as a transverse solid upgrowing ridge of tissue upon the dorsal side. Just behind this lies the fourth ventricle, as already noted (fig. 77, *w*). It appears from above as a triangular dilatation of the central cavity of the medulla, but thinly covered upon the dorsal side.

The elongate brain of the salamander, with its parts outspread almost like a diagram, is very simple in comparison with that of the higher vertebrates (fig. 86). In birds the cerebellum and the optic lobes are relatively larger and in

mammals, and especially in man, the cerebral hemispheres attain their maximum development.

Thus a simple tube of undifferentiated nerve cells becomes moulded into a brain. By localized outgrowths of its walls all the principal external features of its form are wrought out. The subsequent development of fibers from all these masses of cells is a matter far too intricate for us to attempt to follow here. A few of the more salient features of the ultimate distribution of these fibres will be considered in Chapter XI.

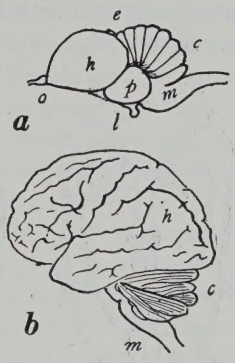



FIG. 86. Brains *a*, of pigeon and *b*, of man; *c*, cerebellum, *e*, pineal body, *h*, hemisphere, *l*, hypophysis, *m*, medulla, *o*, olfactory lobe, *p*, optic lobe.

**The development of the primary circulation.** — In the midst of the mesoderm, tube-like clefts appear, which, extending and becoming confluent, develop into the blood vessels. The first and most important of these appears as a cleft of sigmoid curvature in the region of the throat; and by the processes diagrammatically represented in figure 87, it becomes enlarged, strongly flexed, and divided into compartments, it develops muscular walls, and becomes the heart. It becomes two chambered by the differentiation of an auricle and a ventricle, the former being carried to the front of the latter by the flexion undergone during development. The passage leading forward from the ventricle,

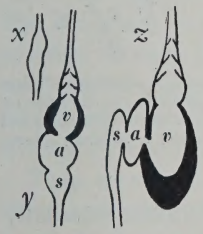



FIG. 87. Diagram of development of the larval two chambered heart. *x*, the primitive cleft of the mesoderm; *y*, the differentiation of chambers and valves; *z*, the completion of the sigmoid flexure; *s*, venus sinus; *a*, auricle; *v*, ventricle.

destined to become the arterial trunk, becomes conjoined with other paired passages in the mesoderm of the throat leading to the gills, which become the branchial arches. Corresponding vessels develop upon the dorsal side and become conjoined with the great dorsal aorta, leading rearward (see figures 88, *x*, and 89). About the time these vessels are

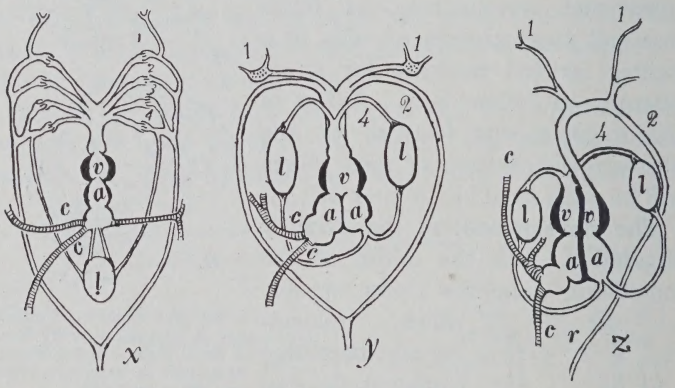



FIG. 88. Diagram of types of circulatory apparatus in vertebrates. *x*, a lung fish (Ceratodus); *y*, a frog and *z*, a mammal. (For the sake of clearness the auricle is turned backward, straightening out the sigmoid flexure.) *1*, *2*, *3*, *4*, the four branchial arches, becoming, in *y* and *x*: *1*, the carotid, *2*, the aortic, and *4*, the pulmonary arches; *a*, auricle; *v*, ventricle; *l*, lung; *c*, cava; *r*, the single root of the dorsal aorta in mammals.

first marked out, gills develop upon the gill arches externally (fig. 85) and become traversed by a system of capillary vessels, which are at this stage the connecting link between the dorsal and ventral vessels just mentioned. The circulation of the blood through these transparent external gills is easily observed with the microscope, and it is a beautiful sight.

This simple type of circulation is essentially fish-like (fig. 88, *x*). There are no lungs as yet, and hence there is no pulmonary circulation. The heart is but two chambered.

All the blood passes forward from the ventricle through the gills, to be returned rearward through the dorsal aorta. The aortic arches are four, and at first essentially alike.

**Development of pulmonary circulation.** — Lungs develop as already noted by outgrowth from the ventral pharyngeal wall, and blood vessels to supply them arise from the fourth branchial arch and extend rearward to penetrate their walls. Return channels are developed, joining the lungs directly with the heart. When these vessels become functional, a considerable part of the blood is diverted from the gills to the lungs. This, however, is of late occurrence, being an accompaniment of the shift from aquatic to terrestrial life. Before it happens the gills begin to atrophy and new channels begin to be developed. A carotid artery springs from the anterior side of the foremost branchial vessel on each side, to carry blood from the heart into the head. A short cut is developed between the dorsal and ventral portions of the branchial vessels of the second pair, thus omitting the passage through the gills. This pair then becomes the aortic arches of the adult salamander, forming a continuous uninterrupted channel from the heart to the dorsal aorta, which ultimately becomes the main channel of the circulation.

Thus we see that in the transformation from larva to adult salamander the fourth arch that springs from the arterial trunk becomes the pulmocutaneous artery; the first arch becomes the carotid, the second becomes the aortic, the third atrophies, or becomes variously connected with adjacent arches, and the branchial circulation first laid down becomes so altered as to be recognizable only by most careful comparison.

The fate of the gill clefts and skeletal arches is no less interesting. The foremost cleft narrows to a tubular passageway, in connection with the outer end of which the ear is developed, and the cleft in part persists as the eustachian

tube leading from the pharynx to the middle ear; this is its fate in most higher vertebrates, and in ourselves. The other clefts close after the atrophy of the gills. The skeletal arches that surround the neck, standing between the clefts, have various fates. The mandibular arch that stands in the wall before the first cleft in the salamander, becomes the

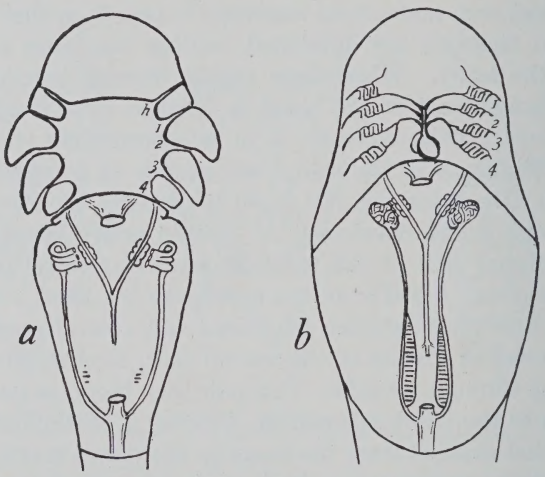



FIG. 89. Diagram of the development of amphibian gill slits gill arches. *a*, is a horizontal (frontal) section of the body of a young larva, showing the relations of the newly formed pronephros to the dorsal aorta in front and to the cloaca behind; *h*, is the hyo-mandibular gill cleft. *1*, *2*, *3*, *4*, the succeeding four branchial clefts; *b*, is a dissection of an older larva, showing the branchial blood vessels, and the true kidneys attaching to the pronephric duct.

mandible, or lower jaw of the adult salamander (note that the tadpole has no mandible, and the form of its mouth is entirely changed in transformation). The succeeding skeletal arches of the larval salamander persist in part as the paired members of the hyoid skeleton shown in figure 71; the foremost of these persists as the single hyoid bone in most of the higher vertebrates and in ourselves.

**The kidney.** — The development of the kidney is no less remarkable. In that part of the cleft mesoderm, which enters into the composition of the body wall (the *somatic* layer) a further cleft appears which develops into a long tube or duct, (fig. 81, *c*, *n*) that extends from a point on the ventral wall of the archenteron, where the urinary bladder will later develop, forward along the wall of the cœlom. At its anterior end several short convolute tubes develop, with their open ends abutting against a dilatation of the dorsal aorta in the cœlom (fig. 89, *a*). Thus, they are probably able from the beginning, by reason of this connection, to remove protein wastes from the blood. These tubules in-

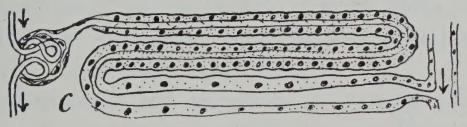



FIG. 90. Diagram of a single nephridial tubule from the kidney. The arrows at the left indicate the course of the capillary blood circulation through the glomerulus; the arrow at the right indicates the path of excreta to the ureter.

crease in number, length and complexity of arrangement and form the *pronephros* or " head kidney."

The true kidney develops later, and much farther back in the cœlom. It begins as separate and isolated tubules developing against the dorsal wall alongside the pronephric duct, into which they later find admittance. The tubules (fig. 90, *c*) increase in number and differentiate internally. Each acquires connection with one of the capillaries joining the renal artery with the post cava. All of one side become combined together in a single organ, the kidney. The rear end of the pronephric duct becomes the ureter; the anterior end (and with it the pronephros) disappears. These changes are diagrammatically indicated in figure 89.

**The skeleton.** — In some very primitive allies of the true vertebrates (as for example, the lancelet, fig. 91,) the notocord persists through life as the chief supporting structure of the body, but in the salamander as in vertebrates gen-

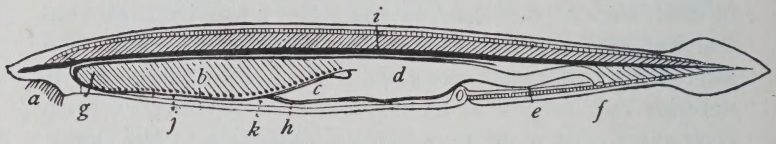



FIG. 91. The lancelet (Amphioxus, or Branchiostoma) after Gegenbaur. *a*, mouth; *b*, gill chamber; *c*, sac of enteron corresponding to the liver; *d*, stomach; *e*, intestine. *f*, anus; *g*, aortic arch; *h*, portal vein; *i*, notocord, with dorsal aorta extended beneath it; *j*, post cava (all the main blood vessels have contractile walls); *k*, cœlom.

erally, it is early replaced by a cartilaginous skeleton. Its cells becomes vacuolated, and are finally reabsorbed and entirely disappear. The beginnings of the development of the cartilaginous cranium about the front end of it are shown for the salamander in figure 133. Cartilage constitutes the whole skeleton of many of the lower fishes, but in the higher vertebrates it is more or less replaced by bone.

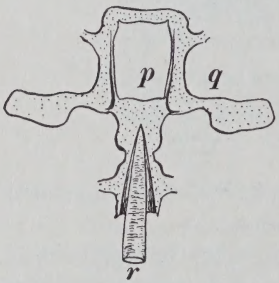



FIG. 92. Front end of notocord in its relations to the cartilaginous base of the cranium in the spotted salamander. *p*, beginnings of cartilaginous cranium; *q*, orbit of eye; *r*, notocord.

**The cellular structure of the salamander.** — We have thus far been speaking mainly of organs; but the ultimate units of organization and of function in the salamander, as in all animals, are cells. Organs are built of tissues, and tissues are composed of cells; each kind of tissue, mainly of one kind of cells.

Cells when consolidated into tissues become difficult to study. Prepared sections become necessary. Only a few

kinds remain free and easy of direct examination. The enormously enlarged yolk-filled egg is one of these. What a hugely overgrown cell it is will be seen if one mounts for the microscope a bit of a stained and cleared ovary where it will be seen surrounded by cells of normal size.

The very minute free-swimming sperms are readily observable. If a fresh testis be cut open and its fluid contents mounted for the microscope the sperms may be seen actively swimming about.

Blood corpuscles, both white and red, may also be observed directly if we thus mount and study a drop of fresh blood. The more numerous red corpuscles (of this color, only when seen in mass), will be of uniform oval contours; the fewer, amœboid, more transparent white corpuscles, of uneven outlines.

We have noted how, through division of the egg, cell increase proceeds. We cannot follow the differentiation of these early cells, which are at first so much alike, as they take on the extraordinary differences of form that will later characterize them as units in the structure of nerve and muscle and gland.

The embryonic endoderm becomes epithelium and is the lining layer of the alimentary canal and of its appendages. It is for the most part a single layer of cells not remarkably modified in form, differing according to degree of crowding. A few typical forms are shown in figure 93. In the pharynx they are compact in form and ciliated on their free border. If a few cells be lightly scraped from the wall of the pharynx of a fresh specimen and then mounted for the microscope, the cilia may be seen in action.

In the intestine they are more columnar, compressed together and slender, and some of them are differentiated as goblet-shaped mucus-secreting cells.

In the stomach where the whole wall is made up of multitudinous pit-like depressions called *gastric glands*, they are differentiated into bulky cells that secrete the digestive fluids at the bottom, mucus-secreting cells along the sides, and protective cells about the mouths of the pits where they come in contact with the food.

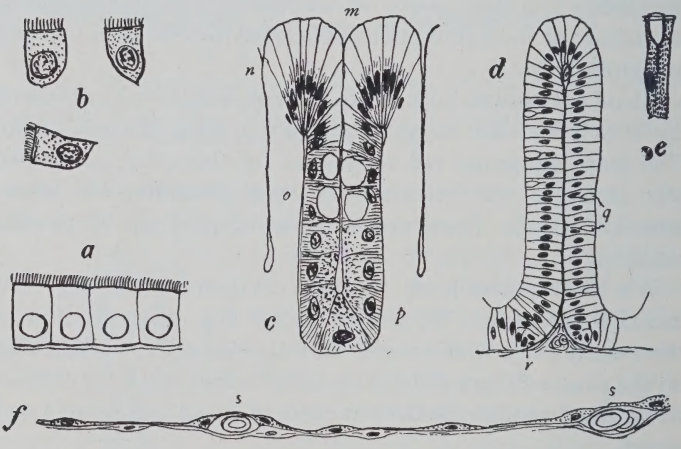



FIG. 93. Diagrams of types of epithelium. *a*, ciliated epithelium of the pharynx; *b*, isolated cells of the same; *c*, a gastric gland from the stomach wall; *m*, its mouth; *n*, the contact layer at the surface; *o*, the middle layer of mucus-secreting cells; *p*, the gland cells of the deepest part (pepsinogen secreting); *d*, a single villus from the wall of the intestine; *q*, goblet cells (mucus-secreting); *r*, a group of replacement cells (center of cell increase); *e*, a single goblet cell; *f*, a bit of the wall of the lung showing the thin respiratory epithelium (stippled); *s*, *s*, capillaries containing blood corpuscles. The underlying muscle layers are not shown.

In the lung, where the extension of the walls is very great, the cells are spread out flat and very thin to cover them. This thinness favors the diffusion of gases between the blood and the air, and is characteristic of respiratory epithelium.

The embryonic ectoderm remains in part on the surface of the body as epidermis. It is several layers in thickness; and as the surface cells wear away or are sloughed off new

cells grow up from the lowermost layer. Vertical sections of the skin will show also large mucous glands that have developed from the epidermis, and that lie mainly beneath it in the thick fibrous underlying dermis, their mouths opening through it to the surface. It is the secretion of these glands that keeps the surface moist, and fit to aid in the uptake of oxygen from the air.

**The salamander, a typical vertebrate.** — Because of its relatively simple structure, the salamander serves well for introduction to the study of the vertebrates. The parts we have found in it are in all the others, only modified in form. As it develops, so do the others, in the main; in all, the principal organs are laid down in like manner and have like relations to the germ layers, and to each other. Neural tube, notocord and gill arches are formed in all: the first, destined in the higher vertebrates to have an extraordinary development; the second, to disappear; the third, to undergo changes so great as to make them scarcely recognizable.

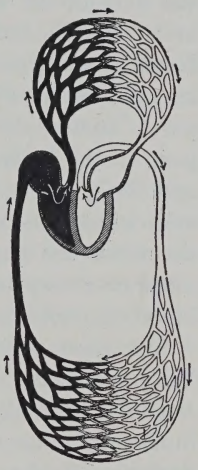


FIG. 94. Diagram of double circulation: capillaries of the lungs above; those of the body below (from Verworn).

A two chambered heart and a fish-like circulation develop first, and a pronephros, before the true kidney; but some develop much farther than the salamander, and along very peculiar lines. The salamander ends its improvement of circulatory apparatus with two aortic arches doing precisely the same work; but in the higher groups of vertebrates, birds and mammals, we find one of these arches has been done away with and the other one does the work alone; the right one has been retained in birds, the left one in mammals (fig. 88, *z*).

The purpose of circulatory apparatus is to get the food to the points where it is needed for use, and to get the waste to points whence it can be removed from the body. When the animal body is small and no part of it is far removed from food supply, there is little need of circulatory apparatus. The amœba may feed at any point of its body. In the hydra, the food cavity, extending to the tips of the hollow tentacles and out into the buds, is not far removed from any cell. Even in so large an animal as a flat worm the food cavity may, by means of extensive ramifications, reach nearly every part. But in all the higher terrestrial forms of animals, the part of the body wherein food elaboration occurs is small, and the greater part of the body is remote from food supply, and circulation of the food is therefore necessary. Likewise, the more the nephridia become localized in the body, the more necessary becomes circulatory apparatus, with definite blood channels leading to them from every part of the body.

But there is circulation before there are blood vessels. We have seen it in Paramœcium; many of the lower multicellular animals also lack blood vessels. There are body fluids occupying the interstices between the cell layers and bathing all the tissues internally. These are the media through which the internal exchange of food and waste materials is effected. These supply the aquatic environment that is necessary for the maintenance of cell life; for cell life, in the beginning aquatic, is in an important sense aquatic still, even in terrestrial organisms. Living protoplasm is a semifluid substance, and metabolism is compatible only with a liquid state.

The fluids of the body are moved about, (that is, circulated) in part by the movements of the tissues which they bathe, and in the higher organisms appear special organs of propulsion. Blood vessels at first appear as short open contractile

tubes, that communicate freely with the cœlom, and that merely serve to keep the blood irregularly moving. When, as in the higher vertebrates they have become completely closed channels, capable of retaining the differentiated red corpuscles and carrying them about the body in continuous procession, they are still supplemented by that intercellular circulation that is due to the contraction of the muscles and movements of the organs. The need of this propulsion of body fluids by body movements is convincingly evidenced in ourselves by the benefit of physical exercise (even though performed by proxy, as in massage), and conversely, by the stagnation induced by too exclusively sedentary habits.

**Ductless glands.** — There are some lesser parts of the body, not belonging to any of the *systems* of organs that we have been considering, that yet are an important part of the one whole system that is the body itself. The spleen is a reservoir of red blood corpuscles. It is filled with a reserve supply of those efficient carriers of oxygen. When a hæmorrhage occurs, the loss of these carriers in the escaping blood is made good by a discharge of more of them from the spleen into the circulation. This discharge is by way of the splenic vein.

The ductless glands all discharge their products into their environing fluid, and distribute them by way of the blood vessels through the general circulation. These are the thyroid, parathyroid, pituitary, and adrenal glands. The thyroid in man consists of two lobes applied to the sides of the larynx, connected beneath it by a narrow belt-like thinner portion. The parathyroids are four minute glands applied to the sides of the thyroid. The pituitary has already been mentioned; it lies above the roof of the mouth attached beneath the brain. The adrenals cap the kidneys. The functions of these will be noticed in the chapter on Organization.

There are more less definite channels (*lymph vessels*)

developed in all the higher vertebrates, for the circulation of the body fluids aside from the blood vessels. These, in our foregoing hasty survey, we have left out of account. But there is one such vessel (the *thoracic duct*) of very great importance in mammals; for by it the greater part of the food enters the general circulation, in the manner diagrammatically indicated in figure 95.

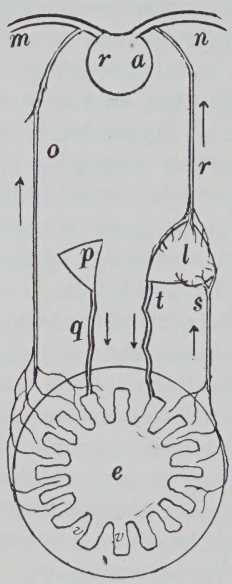



FIG. 95. Diagram of the two main channels by which food enters the general circulation in mammals. *e*, intestine with villi, *v*, *v*, in its walls; *r a*, right auricle of the heart, *m*, post cava; *n*, precava; *o*, thoracic lymph duct; *p*, pancreas; *q*, pancreatic duct; *r*, hepatic vein; *s*, portal vein; *t*, bile duct from *l*, liver: arrows indicate the course of secretions entering the intestine, and of the absorbed food departing therefrom.

**Aquatic and aërial respiration.** — In water, the supply of free oxygen is that contained in the air which the water has absorbed. The simpler organisms, being small, readily obtain a supply by direct absorption through the surface of the body. Increase of size, however, disturbs the ratio between volume and surface in the body. As compensation for the excessive increase of volume, absorbing surfaces are increased by the outgrowth of gills; and then mechanical arrangements for bringing more water into contact with the gills follow. The gills are lodged in respiratory chambers, through which a constant stream of fresh water is maintained but still the amount of oxygen available is much more limited than in free air. There are no warm blooded animals except air breathers.

In the open air, the oxygen supply is inexhaustible: but air absorbing surfaces, such as are adequate for aquatic

respiration, cannot endure exposure to dry air. Some land animals like the earthworm, living in moist places, are able to breathe through the skin, by keeping it moistened with mucus secretion; but if a worm be exposed to a dry atmosphere it quickly dies of evaporation.

The respiratory process, being essentially aquatic, requires moist thin-skinned surfaces for the intake of oxygen, and in organisms that live in dry atmosphere these can only be maintained inside the body; hence, the lungs, reached by long tortuous mucus-moistened passageways and maintaining deep cavities next the respiratory epithelium, where a zone of moisture-laden residual air serves as a medium of exchange and as a buffer to the air waves from the outside.

**The shift to life on land.** — The amphibians make it easy to understand the transition from aquatic to terrestrial life in vertebrates. It would have been hard to imagine all the changes necessary for fitting a fish-like aquatic vertebrate for life on land; but in a salamander these changes, some of which would certainly surpass imagining, are all wrought out in a little while before our eyes; they go forward without a hitch, and most significant of all, they go forward in similar manner, in all the higher terrestrial vertebrates, whether they are to live any part of their lives in the water or not.

The terrestrial life is attained only in part by amphibians. Eggs and young remain in the water and even the adults require a moist environment. Exposed to dry air, the frog or salamander soon dies of evaporation.

Reptiles are mainly terrestrial. They provide their young with an aquatic environment within the egg by adding to a very large yolk an enveloping layer of watery albumen, and on the outside, an impervious shell. The eggs, to be sure, are laid in moist sand or other similar humid places. The young are hatched in a more mature condition. The form of

the adult has been attained before they issue from the egg. Better lungs are developed, and the body is covered with an evaporation-resistent skin. Thus moisture control has been attained but not control of bodily temperature. They are "cold-blooded." The warmth of the body goes up and down with that of the surrounding atmosphere. When it is cold their activity ceases and they hibernate.

Birds and mammals have carried these improvements a step further by the development of a four-chambered heart and a complete double circulation of the blood (fig. 94). All the blood passes through the lungs on each circuit of the body. All the blood thus gathers oxygen on each round. This provides for greater oxidation of food when more warmth is needed, and (together with certain regulatory arrangements to be mentioned in the chapter on Organization) makes all-year-round activity possible in cold climates. Birds and mammals are the "warm-blooded" animals.

**Types of nurture.** — As in the salamander, so in vertebrates generally, the sexes are separate and true sexual reproduction is the rule. But there is very great diversity among them as to mode of nurture of young, and some of the differences are of profound significance. The lancelet (fig. 91) lays minute eggs containing very little yolk; these undergo typical segmentation and gastrulation, and the embryos hatch when they reach the gastrula stage, and thereafter shift for themselves, receiving no further parental nurture. But all the dominant groups of vertebrates make better provision for the development of their offspring. They do not turn them adrift in so immature and feeble and defenseless a condition.

There are two main types of nurture for the young of vertebrates. (1) The storing of additional food supply in the form of yolk in the eggs. We have found a considerable store of yolk in the eggs of salamander; this process reaches

its maximum development in the relatively huge eggs of birds.

(2) The nurture of the young by means of embryonic membranes. This reaches its maximum development in mammals, and it has many features of unique interest and significance, but we can here consider only a few of its more general aspects.

We have already seen in the salamander that a dilatation of the oviduct near its lower end (the uterus) serves for the temporary storage of the ripe eggs, just before their extrusion. In the higher mammals the two oviducts (called also *Fallopian tubes*) become confluent at this portion of their length into a single uterus, in which the eggs on leaving the ovaries find lodgment. Being fertilized internally they remain here, and undergo segmentation and other early developmental changes while in close contact with the uterine wall.

**Embryonic membranes.** — Almost as soon as the primary germ layers are established the ectoderm of the ventral wall rises up about the embryo in a circular fold all about its body and over its back; the edges of the fold come together and fuse and enclose the embryo (or *fœtus*) under a double canopy of thin membrane called the *amnion* (fig. 96, *b*). Almost simultaneously a food absorbing organ called the *allantois* develops for attachment of the embryo to the wall of the uterus. This springs from the endoderm near the posterior end of the archenteron. It grows out as a hollow membranous fold posteriorly and then dorsally between the wider folds of the amnion;. there is developed within the allantois a complete set of embryonic blood vessels, the principal ones being an allantoic artery that springs from the great dorsal aorta, and an allantoic vein that returns the blood to the post cava.

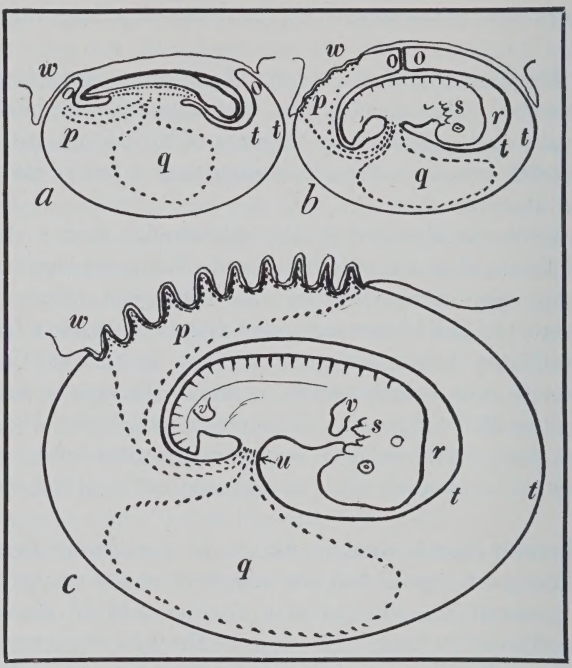



FIG. 96. Diagram of development of embryonic membranes and formation of placenta. ***a, b, c,*** three stages; embryo in the center; ectoderm, *o*, *o*, in solid lines; endoderm, *p*, and yolk sac, *q*, in dotted lines. The uprising folds of the amnion meet and fuse to form the closed amniotic sac, *r*, in which the embryo thereafter floats. The allantois, *p*, arises from the endoderm, turns up over the back, fuses with the outer amnion and becomes interlaced with processes developed on the wall of the uterus, *w*, to form the placenta — the embryonic feeding organ. The yolk sac, *q*, is vestigial and unimportant. The parts of the embryo shown are eye, ear, body segment, tail, gill slits, *s*, and budding limbs, *v*, *v*. The beginning of formation of the umbilical cord is shown at *u*. *w*, wall of the uterus.

The allantois and the outer layer of the amnion become fused together, and attached to the uterine wall in a series of minute interlocking processes (*villi*), the whole complex attachment layer being known as the *placenta*. The processes

on the wall of the uterus become permeated by a dense network of capillaries developed from the blood vessels of the mother. This becomes the source of food supply for the embryo during its long prenatal existence. In the corresponding villi of the membranes of the embryo copious capillary blood vessels are developed as a part of the embryonic circulation: these are its food taking organs. The process of nutrition is one of exchange of blood content between mother and offspring by diffusion through the thin walls of the villi.

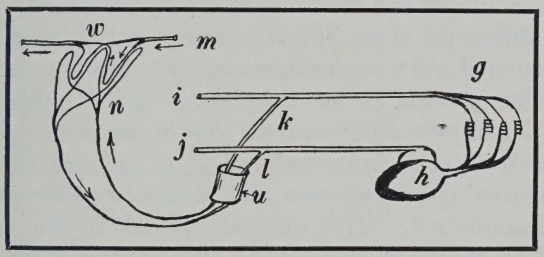



FIG. 97. Diagram of embryonic (fœtal) circulation, arrows showing channels of food intake and waste removal. From the heart of the embryo the blood flows through the gill arches, *g*, into the dorsal aorta, *i*, and allantoic artery, *k*, by way of the umbilical cord, *u* (a small section of it only), to the placenta, where it is spread out in capillary blood vessels. These parallel and lie close to the capillaries of the maternal circulation, *m*, in the uterine wall, *w*. Exchange of food and oxygen for bodily wastes occurs here. The return current is by way of the allantoic vein, *l*, and post cava, *j*, back to the heart.

It is quite comparable to the exchange of gases which takes place in the gills or lungs. Both food (in solution) and oxygen are withdrawn from the passing currents of the mother's blood, and into the same currents are discharged the carbon dioxide and all other waste from the body of the embryo until its birth.

The body of the embryo is immersed within the amniotic sac. This closes to a narrow opening (the *umbilicus*) on the ventral side of the abdomen and the closure elongates into a

long stalk-like umbilical cord through whose vessels nourishment is drawn from the placenta until embryonic growth is ended. The embryo then hangs on the cord, like a ripened fruit upon its stalk. At birth the stalk is severed, and the nutritive organs of the embryo, full formed and functional, are called into action.

Such are the means by which the maximum of provision for development of young is attained in mammals; and to these there is added the development of milk from the mammary glands as a further food supply for infancy. What a vast difference exists in bodily equipment between a new born mammal and the microscopic gastrula of a lancelet!

**The life process** in the salamander and in other vertebrates, is not very different from that in the worm. Indeed, it is much the same in its essentials in all animals, the differences occurring in the ways and means whereby the ends are accomplished. The essential processes are comprehended in the word *metabolism*, and their relation to the accessory phenomena are indicated in the following table:

| | | |
|---|---|---|
| | Food intake<br>Digestion<br>Circulation<br>of food from the alimentary canal<br>of oxygen from the lungs | Accessory processes, physical and chemical |
| METABOLISM | Assimilation (*Anabolism*)<br>Dissimilation (*Katabolism*) | The essential processes: the work of every cell |
| | Circulation<br>of $CO_2$ and $H_2O$ to the lungs<br>of $H_2O$ and N waste to kidneys<br>Discharge of waste | Accessory processes, physical and chemical |

The few animals that we have considered in this chapter, like the few plants in the preceding chapter, are but isolated representatives of vast groups. The principal groups of animals are listed in the following top-heavy table. It is top-heavy in that the higher groups are further analyzed than the lower. The orders of mammals are listed, and the suborders of Primates, also, because we are Primates.

THE PRINCIPAL GROUPS OF ANIMALS

Protozoa, one-celled animals
Metazoa, many-celled animals
- Porifera, sponges
- Cœlenterata, hydroids, etc.
- Platyhelminthes, flat worms
- Nemathelminthes, round worms
- Trochelminthes, rotifers
- Bryozoa, moss-animals
- Annelida, segmented worms
- Echinodermata, starfish, sea urchins, etc.
- Mollusca, clams, snails, etc.
- Arthropoda:
  - Myriapoda, centipedes, etc.
  - Arachnida, spiders, etc.
  - Crustacea, crabs, scuds, etc.
  - Insecta, flies, beetles, etc.
- Vertebrata:
  - Pisces, fishes
  - Amphibia, salamanders, frogs, etc.
  - Reptilia, snakes, etc.
  - Aves, birds
  - Mammalia:
    - Monotremata, duckbill, etc.
    - Marsupialia, opossum, etc.
    - Edentata, sloths, etc.
    - Cetacea, whales, etc.
    - Sirenia, manatee, etc.
    - Ungulata, ox, horse, etc.
    - Carnivora, dog, cat, etc.
    - Rodentia, rabbit, squirrel, etc.
    - Insectivora, mole, etc.
    - Chiroptera, bats
    - Primates:
      - Lemuroidea, lemurs, etc.
      - Anthropoidea, monkeys, apes, and man

## Common Features of Plants and Animals

**Summary.** — All the living creatures that we have now had before us, whether plants or animals, show these common features:

1. Protoplasm is the "physical basis of life," and in nearly all organisms it is definitely organized into cells.

2. Cells, therefore, are the units of organic structure.

3. The method of increase is by cell division.

4. Every organism begins life as a single cell.

5. Aggregates of cells may form individuals of a higher order, with the various parts of the cell complex fitted together in a state of mutual dependence.

6. Two processes are therefore involved in the making of such organisms: (1) cell division and (2) cell differentiation.

7. The fitting of a part of the cells to perform special functions follows the universal law of specialization, that special fitness for one thing involves limitations in respect to other things.

8. The primary differentiation in all the higher organisms is that into germ plasm and body plasm, the former appearing in cells of two complemental sorts, eggs and sperms.

9. Increase in size of the cell complex necessitates supporting structures and circulatory apparatus, but these parts in the different plant and animal groups are exceedingly different in structure.

10. Exposure to the air in terrestrial organisms necessitates the removal of the organs for intake of oxygen from the surface of the body and the development of epidermal layers to withstand evaporation.

11. All make response to conditions of environment, to warmth and moisture, and air, and light; green plants especially to sunlight.

12. All feed and grow.

13. All develop a protective outer covering and maintain a more fluid interior.

14. All store up some reserves of food materials.

15. When, after division, the cells separate organisms remain unicellular; when the cells do not move apart, they become multicellular, and in the latter case the parallel processes of differentiation and division of labor may ensue.

16. Nearly all periodically undergo conjugation by means of sex cells (eggs and sperms, or their equivalent) that fuse in pairs.

17. The series shows trends toward distinct plant and animal types, toward larger, better integrated bodies with better provision for the nurture of the young.

Besides these matters of general organization, there are many other things pertaining to the functions of organisms, to the phenomena of growth and metabolism, to the finer structures of protoplasm and to the behavior of its parts in reproduction, that are common to plants and animals. A few of the better known (cytological) phenomena of the behavior of nuclear parts in reproduction, will be briefly noticed in the chapter on Inheritance.

In short, all living things are composed of one kind of substance, that is organized into equivalent structural units, that increases by one method of growth, and that reproduces successive generations from a common starting point.

CHAPTER V

# PHYLOGENY AND ONTOGENY

## I. Phylogeny

In the foregoing studies we have given brief consideration to a very few plants and animals, selected to illustrate the two main lines of organic development, corresponding to the plant and animal "kingdoms"; but the wide gaps between the types studied have left far too much to be bridged in imagination. Hydra and earthworm, or liverwort and fern, stand so far apart in point of structure that it is difficult to conceive of all the forms intervening. Let us now compare together some forms that are more alike in order to see if possible the nature of the relations that they bear to each other.

Whatever our views of relationship, the series in which we arrange organisms are based on the likenesses and differences we find to exist among them. This is classification. We associate organisms together under group names because, being so numerous and so diverse, it is only thus that our minds can deal with them. Classification furnishes the handles by which we move all our intellectual luggage.

We base our groupings on what we know of the organisms. Our system of classification is, therefore, liable to change with every advance of knowledge. The earliest groupings of animals were very simple and obvious; "creeping things," "flying things," "fishes of the waters," etc. How recently, indeed, have bats ceased to be grouped with the birds, and whales with the fishes. That the very many different sorts

of things living in the water were for a long time merely fishes, is witnessed by the common names they still bear: shellfish, crayfish, jellyfish, cuttlefish, etc., none of which are true fishes. Such classification was based on the recognition of the most superficial characters only. Generally the more fundamental characters are the less obvious ones, and are found in internal organs, and in developmental phenomena.

The earliest anatomical classification of land animals, based on the number of feet — bipeds, quadrupeds, hexapods, octopods, decapods, centipedes and millipedes — was vastly improved when the bipeds and quadrupeds and fishes got together on the basis of the common possession of a spinal column as the group Vertebrata, and all the others were dissociated therefrom as Invertebrata. But the development of embryological knowledge in a later period showed that there are characters more fundamental than the vertebræ; that certain of the invertebrates possess in common with all the vertebrates, pharyngeal gill clefts and a notocord; hence Cordata came to be used unstead of Vertebrata as the more comprehensive group name.

**Homologies and analogies.** — Our judgment of the likenesses between organisms, or between the parts of a single organism, is based on that essential identity of parts that we call homology.[1] Two organs are homologous when composed of like parts in similar relations, each to each. Thus, the hand of a man (fig. 168) and the fore foot of a salamander are homologous, since they are composed of the same parts put together in essentially the same way. On the other hand, when the likeness is superficial only, and not fundamental;

[1] A few exceptional organisms, like certain bacteria, are so simple in structure that differences in their bodily organization are hardly discoverable: and their recognition depends in part at least on their manner of growth in culture media, and in the nature of the by-products of their activity.

when it is likeness in function or in superficial appearance, it is called analogy. Thus the wing of a bird and the wing of a butterfly are analogous organs, for though agreeing in form and function they are totally different in structure, and have no component parts that we can recognize as identical.

Homology is, therefore, the ordinary criterion by which we judge of the relationship of organisms. In the neck of nearly all mammals there are seven cervical vetebræ whether the neck be long as a giraffe's or short as a mole's. The foremost is the atlas vertebra, and bears up the skull; the second is the axis vertebra, about which the atlas swings. The other five, although less differentiated, are equally constant in position and relations, and we cannot doubt but that these seven are identical in mammals generally.

The fore limbs of vertebrates are sufficiently unlike in superficial appearance; we know them as legs in most quadrupeds, as flippers in seals, as wings in birds and bats, and as arms in ourselves; but when we examine their structure we find they are built on a common plan and, therefore, homologous. The recognition of homologies often calls for the utmost care in comparison of organs and for discriminating judgment of a high order. It was a dictum of the great teacher, Agassiz, that the education of a naturalist consists in learning how to compare.

There is beside this correspondence of parts between different organisms, a similar correspondence between parts that are serially repeated in a single organism. This is called *serial homology*. It is well represented in the repetition of parts, segment by segment, in the earthworm.

**Homologies in the wing veins of insects.** — The veins or nervures that constitute the supporting framework of insects wings furnish excellent material for the study of homologies, and they are everywhere procurable. Let us begin by learning

the parts, for we must know them in order to be able to follow their shiftings and changes of appearance and to recognize them under all their disguises.

There are six veins regularly found in insect wings and the names commonly applied to them and the abbreviations for these names are as follows:

| | | |
|---|---|---|
| Costa (C) | Subcosta (Sc) | Radius (R) |
| Media (M) | Cubitus (Cu) | Anal vein (A) |

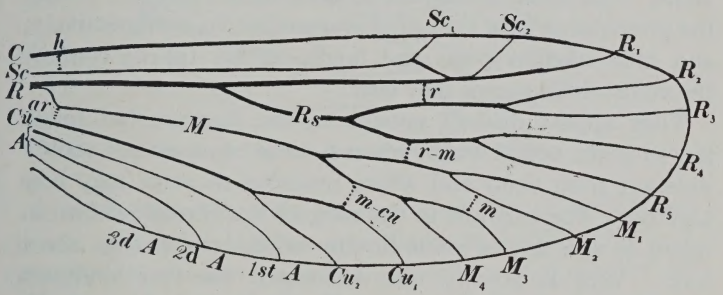



FIG. 98. Diagram of the venation of an insect wing.

Each kind of insect has its own venation pattern. That pattern is made up wholly of these six veins and their connecting cross veins. The costal vein (C) stiffens the front border of the wing. The others radiate outward across the thin wing membrane. Four are branched veins; and their manner of branching and the relation of their branches to cross veins enables us to identify each of them. This may be learned from the accompanying diagram (fig. 98).

The order in which they are named is that of their arrangement from front to rear. Branches of veins are conveniently designated by numerals added in like order to the abbreviation for the vein (as $Sc_1$ and $Sc_2$ for the two branches of the subcostal vein). But there is one large branch so distinc-

tively formed that it has received a special name, the radial sector (*Rs*). All these veins and their usual mode of branching are shown in solid lines in the accompanying diagram of a typical wing. In dotted lines are shown the cross veins of most frequent occurrence. Two of these toward the base of the wing, the humeral cross vein (*h*) and the arculus (*ar*), have received special names; the others are named in accordance with the positions they occupy in relation to the veins. The radial cross vein (*r*) and the median (*m*) occupy the principal forks of the radial and median veins respectively, and radio-median (*r-m*) and medio-cubital (*m-cu*) connect the veins whose names they bear.

They appear distinct enough in the diagram but much less so in the actual wings, wherein cross veins are not visibly different from veins and where branches of veins may fuse together. For example in the wing of the cranefly shown in figure 99 the tips of veins Sc are reduced to a very short fork. Vein R is only four branched, the two hindmost branches having fused together (R4 + 5). Vein M4 and the 3rd A are lost.

If the reader desire a little practice in that common task of the systematist, the tracing of homologies, let him take his pencil in hand and label the wings shown in fig. 100, as figures 98 and 99 are labelled.[1] The stems of the six principal veins will be easily recognized in all, just beyond the level of the humeral cross vein; but the tips may give some trouble.

It will be seen that there are fewer branches in these wings — much fewer in some of them. It is a reduction series. The best flyers among these insects have fewer veins

[1] Enlarged photographs of this figure will provide good material for this. Homologies will stand out more clearly if, when correctly determined and verified, alternate veins be differently colored and cross veins be marked with a third color.

in better adjustment. Cross veins are greatly altered in appearance (but never in their relation to branches).

Assuming that these flies are all descended from a common ancestor having all the veins shown in figure 98, we may by fixing attention on particular features of the wing and comparing part with part, discover definite lines of specialization and thus find indications of their past history.

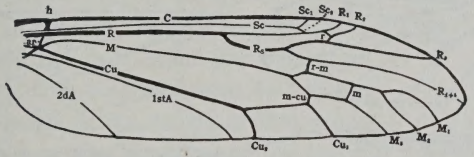



FIG. 99. An actual wing of the cranefly Ctenophora.

It will be seen that vein Sc2 is present only in wing ***b***, and there it is so reduced as to seem like a cross vein. The **cu-a** cross vein has been crowded out in wing **c** by fusion of the veins it conjoins, and this fusion has run to great length in wings **b** and **g**. Likewise the cross vein **m** that is absent only in wing **d**, is turned lengthwise of the wing in **c** and **g**, and in the latter, greatly lengthened.

The tendency of the tips of veins Cu2 and 1st A to fuse from the wing margin inward may readily be followed thus: they approach on the margin in wing ***f***; fuse a little way in **e**; a little more in **c** and **b**, and fuse wholly in **b**.

Wing of **b** (Conops) may furnish a genuine puzzle; for behind R2 + 3 only three vein tips reach the wing margin. What these three are to be labelled may be determined by carefully noting the type of branching of typical veins and the relation of cross veins to forks. Carefully label the veins in each wing with the proper abbreviation at base and apex; do this lightly in pencil, subject to later correction. Mark

fusions of branches with the plus sign between the numerals of the branches conjoined. Follow each main vein stem outward and see when and how often it forks. The proof of correctness will consist in having all parts of the typical wing present or accounted for. Add nothing. Omit to name a vein or branch only when it is considered to have disap-

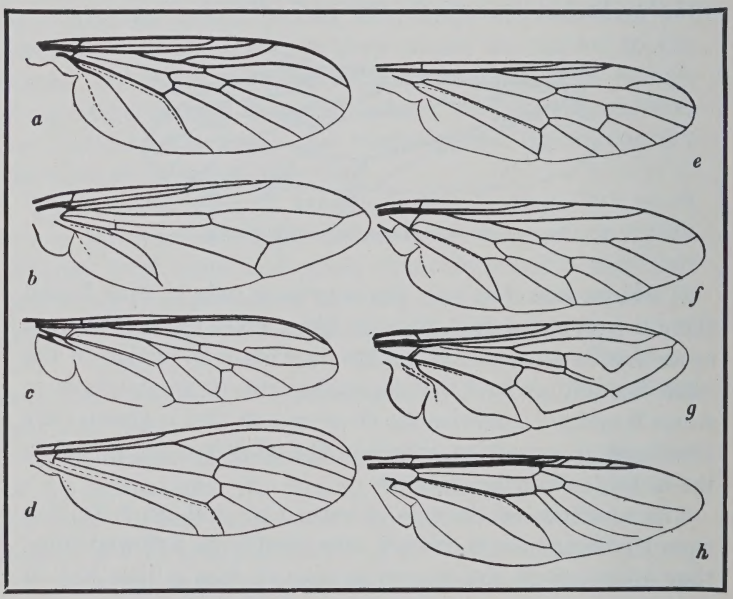



FIG. 100. Venation of the wings of various flies (order Diptera). *a*, Rhyphus; *b*, Conops; *c*, Erax; *d*, Dixa; *e*, Xylophagus; *f*, Thereva; *g*, Eristalis; *h*, Stratiomyia. All from Comstock. The dotted lines are furrows and not veins.

peared by atrophy; veins $M_4$ and 3d A may be so treated. Note particularly that the cross veins are all in their proper places. When correctly interpreted the series will be consistent and harmonious, and the correctness of it will be obvious.

By this means the real likenesses and differences between the members of this group of flies as evidenced by their wings, will have become apparent. This is the sort of study that is used to unravel evolutionary history.

**Genealogic Trees.** — A common means of expressing likenesses and differences among members of a group in a genealogic tree. Such an one for the flies whose wings we have just been considering is shown in fig. 101. This indicates, also, lines of descent from an hypothetical common ancestor.

It should be clear that the two main branches of this tree represent two divergent tendencies in the wings of this group of flies. In one the branches of the radial sector (Rs) have been reduced first in front giving the fusion R 2 + 3; in the other line, first in the rear, giving the fusion R 4 + 5. In the first branch, veins Cu2 and 1st A have tended to fuse together at the tips; in the other branch these veins keep well apart.

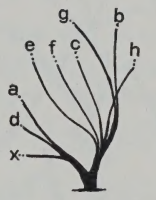



FIG. 101. A genealogic tree based on wing venation, representing the possible relationship of the flies whose wings are shown in the two preceding figures. *x* is Ctenophora, fig. 99.

In such a diagram the more primitive forms are placed nearer the foot of the tree (fig. 101), the more highly developed and specialized at the tips of the longest branches. The others are arranged in positions supposed to represent their degrees of divergence from the primitive type. Each one being at the end of its own line of development is placed at the end of a twig. None is derived from another that is in any respect more specialized.

The lower types in such a series represent the termini of their own lines of development, and are not mere passing stages to higher forms.

The divergence of development stated in the systematic

table on page 153 may be more graphically presented to the mind if the groups contained therein be arranged in such a diagram as is shown in figure 102. Such graphic representations of the possible course of evolution have been much used in the past, in spite of their purely hypothetical character; and they still are excellent aids to the mind in grasping the idea of genetic relationships.

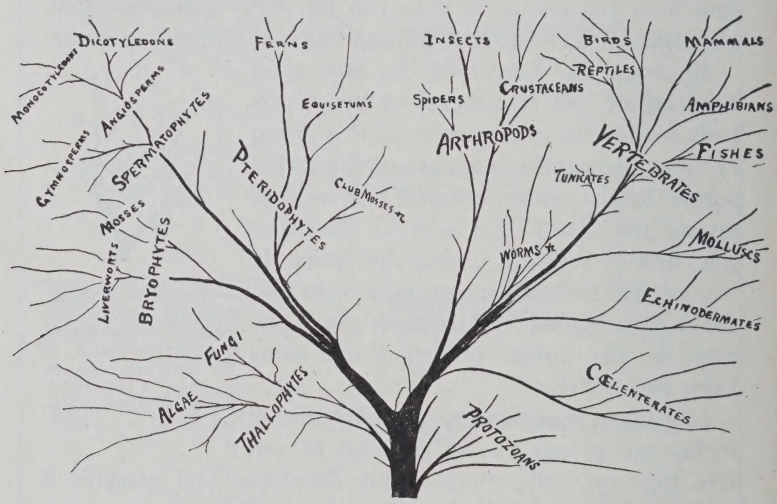



FIG. 102. A genealogic tree; a graphic mode of illustrating possible relationship between organisms.

Genealogic trees generally err in being more explicit than the known facts warrant. The figure of a tree does not present a good likeness of evolution as it lies before us at the present time, because the branches of the tree are conjoined in perfectly definite relations. Lines of development are, in fact, traceable backward only a little way, and are then lost in obscurity. A liverwort that sprawls confusedly over the

soil presents a truer picture of evolution as we see it now. Some of the main branches are clearly conjoined; others stand in doubtful relationships. The ultimate origin of all of them is obscure, for many of the older parts have perished. There is a general divergence of the tips, but there is also convergence, and even crossing. Yet there are enough long stretches of unbroken growth to leave no doubt as to the general course of progress, and there is enough convergence of all lines backward to indicate that all the branches may have sprung ultimately from a common source.

**Serial Homology in Crustaceans.** — This group will illustrate how a single plan of structure may run through a series of forms of the utmost diversity in appearance, and how parts that are essentially alike may be adapted to the most diverse uses.

The Malacostracan body is composed of a series of twenty [1] segments, each of which is essentially of the skeletal plan shown in the diagram (fig. 103), except that appendages of the foremost segment are typically unbranched, and the hindmost segment (the *telson*) is rudimentary and bears no appendages at all. Some of these segments may become fused together and consolidated on the dorsal side, only the appendages and ventral margins remaining free. This may occur at either end of the body, but it occurs constantly in the five foremost segments, these by fusion forming the head. The appendages of these five segments always consist of two pairs of antennæ at the front, one pair of mandibles beside the mouth, and two pairs of maxillæ following the mandibles. Immediately following the maxillæ are one or more pairs of maxillipedes, likewise directed forward beneath the mouth to

[1] This is not counting a vestigial segment in the head region, that is discoverable only during embryonic life, and with which we have here no concern.

assist in the manipulation of the food. Then follow legs and swimmerets in more or less variety, the terminal joints of some of the legs being modified in many cases into highly specialized grasping organs called *chelipeds*, and the swimmerets being frequently modified to serve reproductive or respiratory functions. The eight segments following the head constitute the thorax and the seven last segments (counting the rudimentary 20th segment), the abdomen.

FIG. 103. Diagram of a cross section of the skeleton of a typical body-segment of a malacostracan, with its appendages; *b*, basipodite; *ex*, exopodite; *en*, endopodite.

The typical crustacean appendage consists of a single solid basal piece (*basipodite*) and two jointed branches arising therefrom, one on the outer side (*exopodite*) and one on the inner (*endopodite*). This typical structure is best shown by the swimming legs of Mysis (fig. 104), or by the swimmerets of the abdomen of the crawfish. Crustaceans being primitively free-swimming aquatic animals, it is their swimming appendages that are least altered by adaptation.

The legs are the stoutest of the appendages, and these offer but one branch arising from the basal piece, and that composed of a reduced number of highly differentiated segments. A comparison of a leg with the last maxilliped in the crawfish will show that the exopodite has been lost and the endopodite, preserved and specialized.

Twenty successive rings of chitinous armor-plate, each (except the one at each end) bearing a pair of two-branched appendages — that is the simple plan of the external skeleton throughout all this group! Now see what diversity is wrought out of it. Mysis is rather primitive in that it has retained more two-branched appendages than any of the other forms. Swimming was perhaps the first function of all these append-

ages in the early evolution of the crustacea. The swimming organs are most typical. In all the other forms of this list a number of thoracic appendages have been altered to the form of legs for walking or jumping. The hindmost of these legs in the scud are used for jumping. The nineteenth pair in

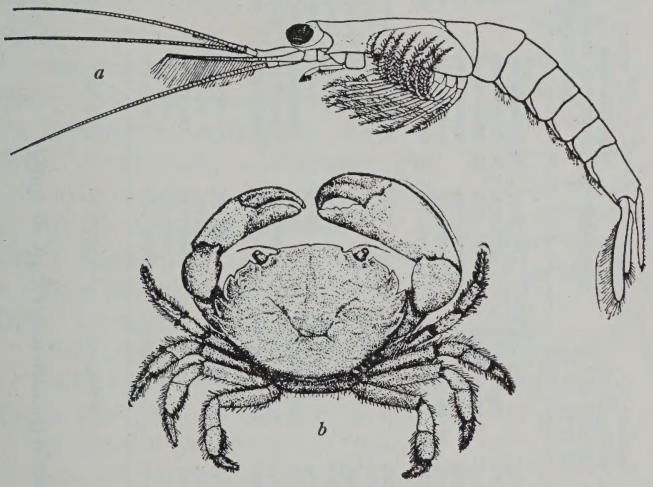



FIG. 104. Extremes of form in Malacostracans. *a*, Mysis stenolepsis (after Paulmier). *b*, A mud crab. (Panopæus depressus).

the crawfish is expanded into a great tail fin by the use of which the animal makes haste backward. In Asellus (fig. 105) the seventeenth and eighteenth pairs are the plate-like gills, that are covered beneath by protective opercula formed from the sixteenth pair. Others are variously modified to serve reproductive or respiratory or other functions, or are lost altogether.

The accompanying table shows at a glance the extraordinary diversity that nature has wrought in this group of

## *Table of Malacostracan Appendages*

| On Segment | | *In Mysis* | *In Scud* | *In Asellus* | *In Crawfish* | *In Crab* | *In Hippa* | *In Squilla* |
|---|---|---|---|---|---|---|---|---|
| Head | 1. | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ |
| | 2. | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ | Antennæ |
| | 3. | Mandibles | Mandibles | Mandibles | Mandibles | Mandibles | Mandibles (8) | Mandibles |
| | 4. | Maxillæ | Maxillæ | Maxillæ | Maxillæ | Maxillæ | Maxillæ | Maxillæ |
| | 5. | Maxillæ | Maxillæ | Maxillæ | Maxillæ (1) | Maxillæ | Maxillæ | Maxillæ |
| Thorax | 6. | Maxillipedes | Maxillipedes | Maxillipedes | Maxillipedes | Maxillipedes | Maxillipedes | Maxillipedes |
| | 7. | Swimming legs | Chelipeds | Chelipeds | Maxillipedes | Maxillipedes | Maxillipedes | Chelipeds |
| | 8. | Swimming legs | Chelipeds | Legs | Maxillipedes | Maxillipedes | Maxillipedes | Chelipeds |
| | 9. | Swimming legs | Legs (3) | Legs | Chelipeds | Chelipeds | Legs | Chelipeds |
| | 10. | Swimming legs | Legs (3) | Legs | Legs | Legs | Legs (7) | Chelipeds |
| | 11. | Swimming legs | Legs (3) (5) | Legs | Legs | Legs | Legs (7) | Legs |
| | 12. | Swimming legs | Legs (3) (5) | Legs | Legs | Legs | Legs (7) | Legs |
| | 13. | Swimming legs | Legs (3) (5) | Legs | Legs | Legs | Legs | Legs |
| Abdomen | 14. | Swimmerets | Swimmerets | Vestigial | Swimmerets (6) | Swimmerets | Swimmerets | Gill |
| | 15. | Swimmerets | Swimmerets | Vestigial (4) | Swimmerets (6) | Swimmerets | Swimmerets | Gill |
| | 16. | Swimmerets | Swimmerets | Gill covers (2) | Swimmerets | Swimmerets | Swimmerets | Gill |
| | 17. | Swimmerets | Swimmerets (5) | Gills (2) | Swimmerets | Swimmerets | Swimmerets | Gill |
| | 18. | Swimmerets | Swimmerets (5) | Gills (2) | Swimmerets | Swimmerets | o | Gill |
| | 19. | Tail fin | Swimmerets (5) | Tails | Tail fin | Tail fin | Tail fin (7) | Tail fin |
| | 20. | o | o | o | o | o | o | o |

(1) Bears a gill-bailer externally.
(2) The foremost forms an operculum, covering the others.
(3) Gill-bearing at the base internally.
(4) Wanting in the female.
(5) Used also in jumping.
(6) Modified for copulation in the male.
(7) Adapted for digging.
(8) Vestigial.

Malacostracan crustaceans out of these two-branched appendages.

Let us now compare together single representatives of five of the orders of higher crustaceans (Malacostraca) as follows:

Order Mysidacea; Mysis, a free-swimming deep water form.

Order Isopoda; Asellus, a bottom sprawler in brook beds.

Order Amphipoda; Gammarus (fig. 106), a scud, a clamberer amid green vegetation in ponds.

Order Anomura; Hippa, a burrower in sandy seashores.

Order Decapoda; Cambarus, a crawfish, a long-tailed decapod; swims backward; lives under cover.

Order Decapoda; Panopæus, a crab, a short-tailed decapod; bottom sprawler; does not swim at all.

Three of these crustaceans, crawfish, asellus and scud, are everywhere available in inland waters, and living specimens will well repay comparison, even if the other marine forms are not readily obtainable. It should be interesting to observe in these three how different are the ways in which appendages are modified to serve the respiratory function. Here are three suggestions of things to look for:

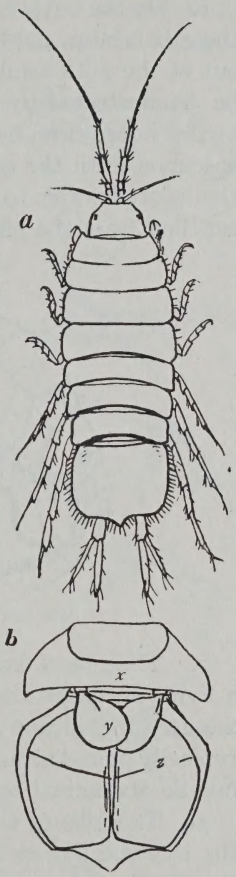



FIG. 105. Asellus aquaticus (after Sars). *a*, dorsal view; *b*, ventral view of abdomen of female; *x*, last segment of thorax; *y*, appendage of abbreviated first abdominal segment (the second segment is without appendages in the female); *z*, gill cover (*operculum*).

1. On the outer side of the second maxilla in the crawfish there is a large gill-bailer, that draws fresh water forward out of the gill chamber, aërating the gills. Its effect may be demonstrated by holding the point of a copying pencil in the water close beside the base of a hind leg of a living specimen until the color dissolves a little, and watching for the colored water to appear at the front of the animal when expelled from the gill chamber.

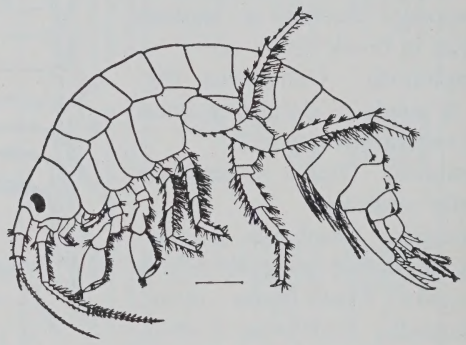


FIG. 106. Gammarus fasciatus (after Paulmier).

2. The gills of Aselus may be studied in action by turning a living specimen over on its back and watching them under a lens. Significant are their texture and form and their typically paired arrangement beneath the greatly abbreviated middle abdominal segments.

3. The gills of Gammarus are appended to the bases of the thoracic legs on the inner side, and the brood pouch of the female is formed between the leg bases.

**Group radiation.** — Perhaps the most striking of the phenomena of divergent development is that which has been called *adaptive radiation*. This name serves to designate that tendency seen in the members of all the larger groups

of organisms to become adapted to different natural functions, and to take on structural peculiarities suited thereto. The phylogenetic lines *radiate* outward, as it were, from common structural type, into forms adapted to herbivorous or carnivorous, aërial or aquatic, or other more special modes of life.

Feeding and locomotion are the two general animal functions that require the most special tools (fig. 107). The accompanying marginal figures will serve to bring to mind how very diverse are two such organs, beak and feet, in birds. Any dominant major division of the animal kingdom, even

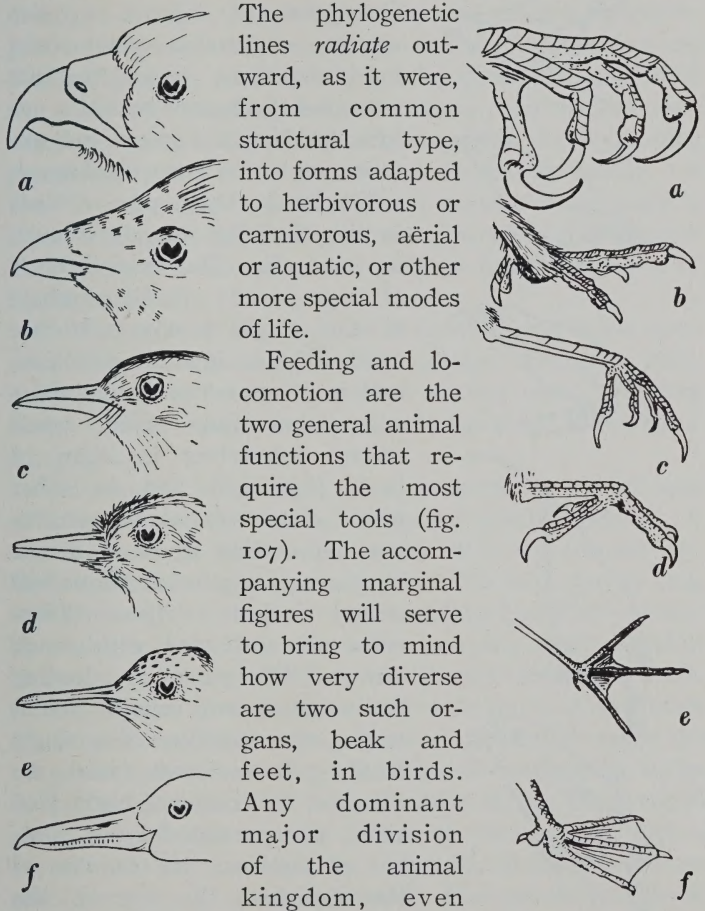



FIG. 107. Beak and feet that go together in common birds, typifying their respective families. *a*, hawk; *b*, grouse; *c*, catbird; *d*, woodpecker; *e*, sandpiper; *f*, duck.

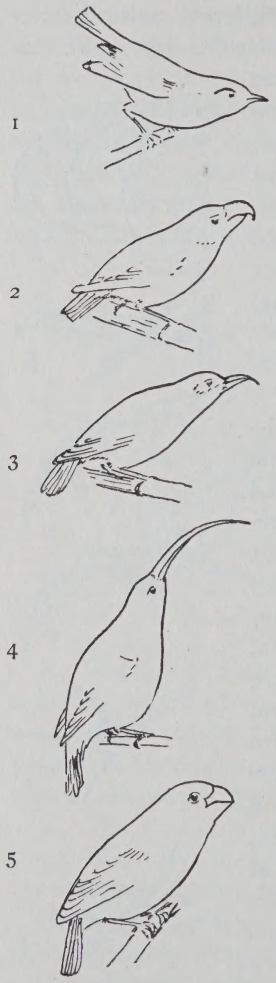



FIG. 108. Hawaiian birds of the family Drepanidæ (after Jordan and Kellogg). *1*, Oreomystis; *2*, Pseudonestor; *3*, Heterorhynchus; *4*, Hemignathus; *5*, Chloridops.

single orders when of dominant types (such as the great order Coleoptera of insects, 150,000 species), will furnish equally striking illustrations. Indeed the best examples of adaptive radiation are furnished by small groups that are dominant within a restricted range.

The family Drepanidæ of birds in the Hawaiian islands is such an example. The singing birds of these islands are all members of this single family. All are much alike in internal structure, and in all essential family characters, but they differ much among themselves in form of beak (fig. 108) and in other minor characters, as the accompanying outline figure of a few representative selected forms will clearly indicate. These differences are correlated with much greater differences in feeding habits than are usually found among the members of a single family. In our own fauna, for example, this order of birds (Oscines) is represented by a number of families: the families of the thrushes, the finches, the orioles, the warblers, the sparrows, etc., in each of which there is found one form of bill, and a general family resemblance. But

the single family Drepanidæ, in exclusive possession of the Hawaiian field, without competition except among its own members, appears to have been developed along many divergent lines in adaptation to all the natural functions that are fulfilled by many families of the order elsewhere; and there are stout seed-cracking finch-like beaks, and slender leaf-searching warbler-like beaks, and many other forms of beaks possessed by the different members of the one family. A like diversity of group development upon a larger scale is found among the pouched mammals (marsupials) of Australia, and another example among the cat fishes (Siluroids) of South America.

**Convergence.** — Convergence of development is less common than divergence, probably because divergent lines, radiating outward from a common starting point, are more likely to enter vacant territory, and thus avoid the stress of competition.

Convergence is manifest in the superficial resemblance of forms that are in essential characters widely different. A familiar example is furnished by the swift and the swallow, birds so similar in appearance and habit as to be readily confused by a novice; indeed, they were long classified together by ornithologists. But they differ in nearly every essential character, and are members of different orders of birds. A comparison of their feet will reveal some of the more obvious external differences. Those of the swallow are of the song-bird type of covering; a series of overlapping scales down the front of the " tarsus " and a single, sharp-edged plate behind (as in the tarsus of the catbird, figure 107, c.); and the toes, counting from the hind toe outward are successively 2-, 3-, 4- and 5-jointed. The tarsus of the swift is " rather skinny than scaly," and the toes, taken in the same order, are 2-, 3-, 3- and 3-jointed. Moreover, the tail

feathers of the swift are spiny-tipped, as in the woodpeckers, with which it has more affinity than with the song birds.

A special phenomenon of parallelism, affecting more superficial characters will be studied in Chapter X under the name of mimicry.

**Palæontology** offers the actual record of the past history of organisms. This record consists in their fossil remains, buried and preserved in the crust of the earth. It is a very fragmentary and incomplete record; for only the hard parts of organisms are capable of preservation in the rocks. Therefore, the more soft-bodied and primitive forms disappear, and leave no trace. The parts preserved as fossils are merely fragments of organisms; shells of molluscs; teeth and bones and armor plates of vertebrates; wings and legs of insects, leaf and stem prints of the larger plants. The uncovering of such specimens demands the greatest care, and the study of them demands the greatest knowledge of corresponding parts in living forms. Yet, notwithstanding the necessary defects of the material, the best specimens, and more especially, the best series of specimens, are of the highest scientific value. The degree of perfection seen in the preservation of structures even so delicate as the venation of an insect's wing, is truly remarkable when one considers the long processes of fossilization through embedding in sedimentary rocks. Figure 109, for example, is a fossil dragon fly. It is a mere impression upon the surface of a slab of lithographic stone from a Bavarian quarry, but how completely are most details of the venation preserved.

Although palæontology has only the hard parts to deal with, every trace of nerve and muscle and every other vital part having vanished, yet the case is not so hopeless as might at first appear, for the hard parts, although dead parts, are the permanent defences and supports which the

living substance has fashioned, in accordance with its needs and hereditary tendencies. The living substance in every group builds its hard parts on architectural lines of its own.

The parts of organisms are so correlated that missing parts may often be inferred from those that are known. The scattered bones of a fossil vertebrate tend to reassemble themselves in the mind of the palæontologist; there is but one way in which they will go together consonantly to form a possible organism; finding that, a picture of the living organism arises vividly in his mind; and if he draw it on paper, it is what we call a restoration.

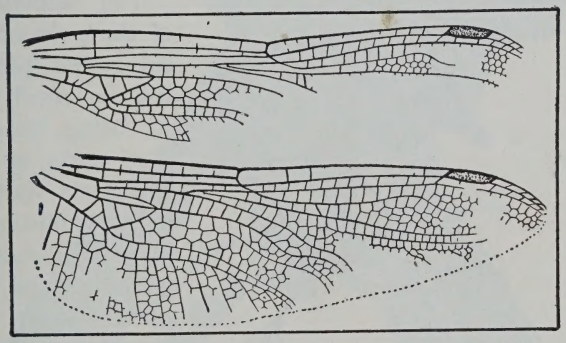


FIG. 109. Wings of a fossil dragon fly (Æschna muensteri), drawn from a specimen in the museum of Comparative Zoölogy at Cambridge, Massachusetts.

It would take us too far from the field of our practical studies of living organisms were we to attempt to consider even briefly the vast wealth of knowledge of extinct forms of life that palæontology has brought to light. For such information recourse must be had to the textbooks, or to the chapters on palæontology in general treatises of zoölogy and botany. We may say of organisms, as, in another sense, the poet Bryant said of men,

"All that tread
The globe, are but a handful to the tribes
That slumber in its bosom."

Hosts of forms, many of them highly specialized, and some groups once dominant have entirely disappeared from among the living, and the aspect of existing groups has vastly changed during the course of their racial history.

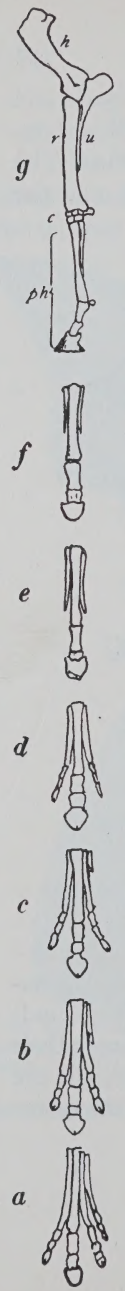
FIG. 110. Archæopteryx (after Zittel). *cl*, clavicle; *co*, coracoid; *sc*, scapula; *h*, humerus; *r*, radius; *u*, ulna; *c*, carpus; *I, II, III, IV*, digits.

The imperfection of the palæontological record proceeds not so much from its being based on hard parts, as from the fact that the more primitive and more significant organisms lack such parts, and are, therefore, dropped from the record, while the more specialized, although having that degree of hardness which renders them best preserved, are the forms that are least instructive as to genetic relationships. But, notwithstanding these things, the

record is clearly one of progress in differentiation of parts and in complexity of organization. Seed plants and backboned animals are absent from the older strata of the earth's crust. The forms at present living are most like the later fossils, and the

FIG. 111. Archæopteryx: a restoration (after Flower).

farther we go back among the older strata, the more unlike existing forms do the fossils become. Synthetic types abound: i. e., forms combining characters of two groups that are in their living representatives sharply separated. Such a type is the famous Archæopteryx (figs. 110 and 111) whose discovery




brilliantly fulfilled Huxley's prediction (based on comparative anatomy) that the groups of birds and reptiles would be found to be confluent in origin. Archæopteryx is a bird possessed of teeth and a long tail, and other structural characters more like to modern reptiles than to modern birds.

Among fossils there are occasionally found more or less continuous series of forms, successively more primitive in the successively older geologic formations. To American palæontology belongs the credit of discovery of one of the most famous of these, illustrating the phylogeny of the horse. Possible stages in the development of the single-toed hoof of the horse as found in fossils are represented in figure 112. And it may confidently be believed that more such series would be found were the fossils better known. Palæontology is continually filling the gaps between the groups of recent species.

**The persistence of the unspecialized.** — In accord with abounding testimony of palæontology that throughout the history of organisms the strong and the well-equipped have frequently dropped out of the race for life, and in spite of the obvious structural advantages of the higher types, we still have amœbas and other very simple organisms flourishing in our midst. How have they withstood the stress of competi-

FIG. 112. Diagram illustrating the skeleton of the foreleg of the modern horse (*g*), and a series of fossil forms (*a* to *f*) apparently illustrating its phylogeny; *h*, humerus; *r*, radius; *ul*, ulna; *c*, carpus; *ph*, phalanges; *a*, Orohippus; *b*, Mesohippus; *c*, Miohippus; *d*, Protohippus; *e*, Pliohippus; *f*, Equus, the modern horse.

tion with forms that appear to be so much better equipped? Why have they not all been exterminated? It may not be possible to say how any particular organism has succeeded, but we do well to remember, first, that size and specialization and organization have their disadvantages as well as their advantages, and second, that most specializations occur in adaptation to removal into new fields or into new spheres of activity. Great size may entail great peril in times of scarcity of food. It takes much food to nourish a large organism. A dozen rabbits may fatten where one buffalo would starve. Specialization always means fitness for one set of conditions, and is apt to be disadvantageous when conditions are suddenly altered. Complexity of organization is always a peril. A horse may fall and break its neck, but hardly may a hydra. The mechanism with fewest parts and least complicated adjustments is the one that will best stand rough usage.

This persistence may be further illustrated by an analogy. Reaping machines have had an evolution, almost within our own time. The forms that have successively appeared (and that have successively been dominant) are the sickle, the scythe, the cradle, the reaper, binder and the combine, and these form a series, so to speak, of increasing size, efficiency and complexity of structure. The advent of each new form has only limited the field, has not crowded out its predecessors. All are in use still. The larger machines are adapted only to broad and open fields; the cradle that once reaped the fields is now restricted to the stump-patch or rocky hill slope; and the sickle finds its place in the edging of the shrubbery or the corner of the garden. All persist together, and the simplest of them is likely to persist longest.

In the second place, these simple aquatic organisms have remained in their primitive haunts of safety, in the ooze of the bottom, or among sheltering stems or rocks, where more

or less out of the way of direct competition with stronger forms, and where no sort of cataclysm could well annihilate their whole tribe. These circumstances, combined with a good reproductive capacity, make for persistence.

**Regressive development** in whole organisms has occurred most frequently as an accompaniment of the parasitic manner of life, and parasites, therefore, furnish its best illustrations. These will be discussed in a succeeding chapter; but retrograde development in the parts of organisms may be noted here.

Most functionless organs, like the human tail (*coccyx*), are vestigial structures. They are developmental heirlooms; useless and unnecessary, but handed down by heredity. There is no other explanation for their existence.

Often loss of function has accompanied a change of habit or of habitat. The bladderwort (Utricularia) is descended from terrestrial plants, but now lives wholly submerged beneath the surface of the water. Abundant stomates, now useless and imperforate, as in aërial plants, have doubtless been carried over from aërial into aquatic life.

Many such shifts have taken place in the phylogenetic development of the human body. The greatest of them must have been from water to land, from horizontal to erect attitude, and more latterly, from savage to civilized conditions of living; and the vestigial structures are so numerous in man's body that it has been called " a museum of antiquities." The best known of these waning organs of vanished function are the vermiform appendix, the muscles for wagging the ears, the " wisdom teeth," and the hairy covering of the skin. Admirable examples of vestigial organs are the rudimentary lung and the pelvic girdle of the snake.

**Specialization by reduction.** — It is important to note that the dwindling and loss of parts is generally a gain to their

possessors. Organs are of no moment except as they serve the organism. The series of insects whose wings we have studied all show decided improvement in capacity for sustained, speedy and well directed flight, as the reduction of redundant, and the readjustment of the remaining veins proceed. It is a sign of a generalized condition when many parts of an organism are found performing similar functions. The earthworm is very generalized in the almost unending repetition of like parts in successive segments.

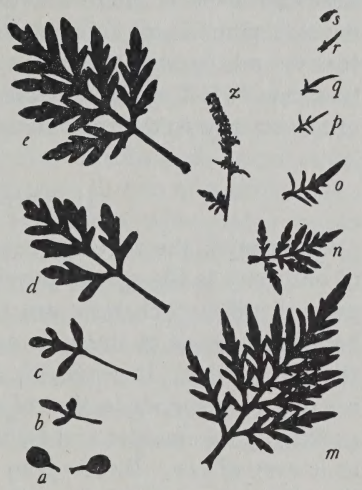



FIG. 113. Leaves of the ragweed (*Ambrosia artemisæfolia*). *a*, cotyledons; *b* to *e*, leaves successively formed in youth, *m*, the mature leaf form; *n* to *s*, the diminishing series of leaves successively formed during the period of seed production; *z*, a fruiting tip.

**Progress in regression.** — There is an important sense in which regressive development spells progress. One must take into account the whole manner of life of the organism to comprehend this. Even the most abject parasite, losing all organs for independent existence, is advancing in its own peculiar way of getting on in the world.

There is also a sense in which regressive development is to be considered a part of the normal life of an individual. As nutritive and reproductive functions come successively into dominance in the lifetime of every organism, so a retrograde development of nutritive organs may begin with the taking up of the labor of reproduction. This is well illustrated

by the common ragweed. The leaves shown in figure 113 were developed at different periods of the life of a single plant. They are divided into two series, which parallel the wax and wane of vegetative vigor in the plant. The second series is the one of interest here; it begins with the maximum development in size and complexity of leaves at sexual maturity, and, passing through a diminishing series, ends with cessation of leaf production when all the energies of the plant are given over to the ripening of its seeds.

## II. Ontogeny

Ontogeny is the development of the individual. The study of ontogeny is the special province of embryology, since the more significant changes are those which precede birth or hatching. Some of these changes we have already noted in the salamander. It begins life as a single cell. Its structure roughly corresponds to that of a protozoan. It is, of course, as much a salamander and as little a protozoan at that stage as it ever will be. But its plan of bodily organization is very like that of a spherical single-celled protozoan, and very unlike that of an adult salamander. By segmentation, a blastula is formed, which is very like Volvox in plan, since both consist of a hollow sphere of cells. Then the inpushing of the wall of the sphere makes of it a gastrula, which is much like a hydra, in that there are now two layers of cells surrounding a simple food sac. The correspondence between gastrula and hydra extends only to general body plan — not at all to the specialized parts of the mature hydra; it is rather to a late embryonic form of the hydra, but to one old enough to show the final plan of body well established.

And so the wonderful process goes forward, yielding by the simplest means results that not the boldest imagination

could ever have conjectured.[1] Each new feature reveals some characteristics of a higher type, and each is soon merged with others still newer.

The mesoderm appears, and cleaves apart to form the cœlom: then neural tube and notochord; a heart upon the ventral side and gill slits appear, and it is evidently a vertebrate. But at first it appears to be a vertebrate of very primitive type. It has gills, and a two-chambered heart, and a fish-like circulation. Then, more slowly, as we have already seen, these characters are merged into those we call amphibian, and finally it appears in the completed form of a salamander, consonant in general with its species and tribe, and in particular with its immediate ancestors, in form and feature, in proclivities and habits, in faculties and in action.

What a marvel of potentialities is the egg cell! What a marvel of performance is the simple cell-mass we call an embryo, that races down the main travelled road of its phylogenetic history, never going astray though countless paths diverge, and only slackens its speed when nearing its proper destination!

In the post-embryonic development of the salamander there are alterations of organs that may be summarized in five categories:

1. There are organs peculiar to the larval stages and

[1] "There is nothing, either in the aspect or in the internal composition of the (hen's) egg, which could lead even the most daring imagination to conjecture that it was hereafter to turn out from under its shell a living perfect bird. The form of the egg bears not the rudiments of resemblance to that of the bird. Inspecting its contents, we find still less reason, if possible, to look for the result that actually takes place. If we should go so far, as, from the appearance of order and distinction in the disposition of the liquid substances which we noticed in the egg, to guess that it might be designed for the abode and nutriment of an animal, (which would be of very bold hypothesis), we would expect a tadpole dabbling in the slime, much rather than a dry, winged, feathered creature." — Paley.

wanting in the adult. Such are the gills, the tactile palps and the tail fin (in the frog, the entire tail,) etc.

2. There are organs that are functional in the larva and vestigial in the adult. Such are the head kidney and the hinder gill arches.

3. There are organs that are present in both, with a changed function in the adult. Such is the gill cleft that serves the young larva for respiration, and that becomes the eustachian tube leading from the pharynx to the ear in the adult.

4. There are organs that are present in both but that are better developed in the adult. Such are the eye, the heart and the brain.

5. There are organs that are rudimentary or absent in the larva and functional only in the adult. Such are the skin glands that keep the surface of the body moist during life on land; and the sex organs.

6. There are organs that necessarily perform like functions in both, but that become altered at time of transformation to suit the change of habit. Such are the intestine which becomes shorter in adaptation to a diet more strictly animal food; and the brain which becomes larger with need of new activities connected with life on land.

The development of the salamander is but one example of that correspondence between embryonic forms and general plans of adult structure that is exhibited in all the groups. The study of this correspondence by embryologists gave rise to the " biogenetic law " (which is, rather, a rule with many exceptions), that " Every animal in its development tends to repeat in embryonic stages the successive types of structure of animals lower in the series to which it belongs." But this is only a tendency, due to common origin, and a common mode of development. The correspondence is always remote, as

we have seen; not to details of adult structure, but to the simplest expression of the structural type, and it may be perverted by any cause, internal or external, that can modify developmental stages independently. It is commonly obscured:

(1) By abbreviation of the ontogenetic record. Developmental stages, normal to the higher members of a phylum, may be dropped out of ontogeny. Thus the free-swimming nauplius stage, common to most of the Crustacea, does not appear (as a free-swimming stage) in the development of the crawfish; it is passed over in the egg before hatching.

(2) By the coming into predominance in growth of some part of late acquisition in phylogenetic history. The development of the brain in the higher vertebrates is certainly of this precocious sort. The huge brain of the embryo of a bird or a mammal can by no means be regarded as primitive, although it early develops to great proportions in the embryo.

(3) By independent specialization of some of the developmental stages. This is of the commonest occurrence with free living larvæ, which may be specialized in relative independence of adults. The balancers of salamander larvæ, present in one species of Ambystoma (*A. punctatum*) and absent in another closely allied species (*A. tigrinum*) are examples of this.

The immature stages of mayflies offer a superb example. Adult mayflies are much alike in form and habits, but adult life is very brief and is concerned only with reproduction. The struggle for existence has fallen mainly upon the immature stages and these have differentiated and have become very unlike. In becoming fitted for life in diverse aquatic situations they have specialized independently.

The study of embryology furnished a new criterion of

homology. In addition to correspondence in parts and relations of parts in adults, fundamental likeness has to be judged also by correspondence in development. This is indeed the sort of likeness that shows how deep-seated is the homology — the likeness that goes back to correspondence in mode of origin.

Embryology has also vastly extended the field in which homologies may be determined; for, owing to the primitive conditions prevailing in the embryos, their parts may often

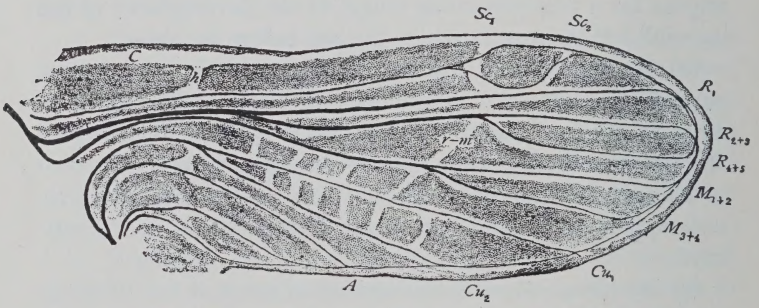



FIG. 114. Wing of the nymph of a stonefly larva showing tracheæ, or air tubes, of the wing, with the veins developing about them and between them; note the absence of tracheæ from cross veins, and the lesser angulation of the tracheæ than of the veins.

be readily compared and seen to be identical, when in adult organs all likeness has disappeared. That the coracoid process of the human scapula is in reality the equivalent of the separate coracoid bone of the vertebrate shoulder girdle is at once evident when its development is studied; for it arises as a separate bone and has at first the usual position and relations of that bone, and later becomes anchylosed with the scapula.

Such difficulties as exist in determining what are the principal veins of a stonefly wing, and what is the mode of their branching, disappear when one studies in the immature wing

the arrangement of the tracheæ, about which the veins are formed.

The correspondence between ontogeny and phylogeny suggests an explanation of hosts of vestigial structures found in embryos. They are inheritances out of the past. Such are the rudimentary incisor teeth of cattle which

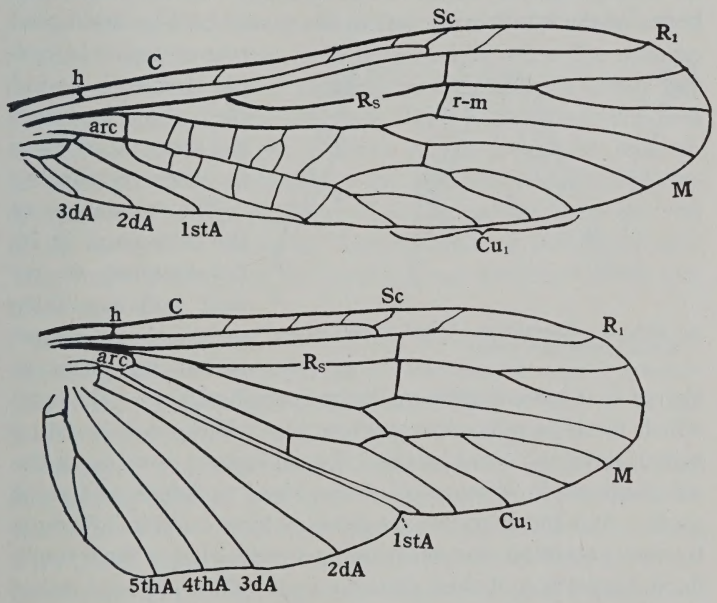



FIG. 115. Wing of an adult stonefly (Isoperla).

though present in the embryo never cut the gums, and are wanting in the adult animal. Some of them are useless old heirlooms, of no practical consequence; and many of them are of no value save as they condition the development of other parts. Such are the gill-pouches of bird and mammal embryos; these appear, only to disappear again (save the

foremost slit, in connection with which the eustachian tube of the ear is developed), and no gills are formed in connection with them.

Ontogeny often explains the absence in the adult of parts that might be expected. Thus, the carpus of a bird appears to be represented by but two bones, if we study only the bones of the adult bird; but in the young bird an additional row of separate carpal bones is found (fig. 116) in much the same relations as in other vertebrates.

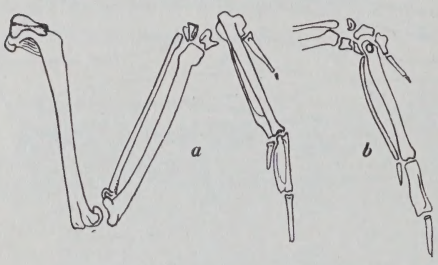



FIG. 116. The wing bones of a fowl. *a*, adult grouse; *b*, young duck (after Coues).

The tendency of the individual in its development to repeat and reproduce ancestral characters is but the outward sign of that inward force we designate as heredity — the force which tends to make like produce like. Perhaps it is only a sort of developmental inertia. Racial history flows on in the old channels in absence of obstructions sufficient to turn it aside. And the channels are guarded from outside influences by the protection that most living species give to their young during a portion of their development. They are kept out of harm's way.

How much more alike are the early embryos of vertebrates than any of their subsequent stages. Wherefore our systems of classification of organisms have tended to be based more and more on developmental phenomena. The bipeds and quadrupeds of old were merged as mammals, animals that suckle their young; and the primary division of mammals became placentals and aplacentals — those that nourish

their young before birth through the agency of a placenta and those which do not so. Similar illustrations abound in all the higher groups.

Palæontology makes known to us the life of past ages, by interpreting such fragments of organisms as have actually come down to us. Embryology furnishes historical data of a very different sort — not the organisms of the past, but of the processes of the past, in so far as preserved in the making of the organisms of the present: not armor nor bones nor any other finished parts of organs, but the moulding processes of the basic materials out of which all the organs are formed. In these processes embryology gives us evanescent glimpses of the ground lines of phylogeny in so far as they are preserved in the successive stages of development of the individual. That many features of all embryos are ancestral there can be no doubt.

It was the study of embryology that did most to compel the acceptance of the doctrine of evolution in a past generation. And it was this also that stimulated to greater use of the historical method in all fields of investigation.

Ontogeny has long been and will ever be one of the most stimulating fields of biological investigation. It is the most synthetic of all. In the bewildering array of forms, it finds a few main types of development, themselves traceable to a common origin in the egg cell. And it shows, withal, how little Nature creates: how much she merely transforms and adapts.

## CHAPTER VI

## EVOLUTION

It has long been the custom of naturalists to arrange organisms in series; such arrangement facilitates dealing with large numbers. The comparative anatomists of the first half of the 19th century, who did so much to advance biological knowledge, believed in special creation, and in the fixity of the species. They determined homologies with great conscientiousness and arranged organisms in natural groups; but for them, homology meant likeness in structure merely, and not kinship, and their groups were "natural" in the sense that like had been associated with like in them. The organisms of a series were no more related to each other than a series of one type of vessels made by the same potter. Why then do we consider that natural grouping signifies blood relationship? Why are the series we arrange evolutionary series to us?

It is because evolution alone affords a consistent and satisfactory explanation of the facts now known concerning the structure, the development and the past history of organisms. The student who has done the work hitherto outlined will have *felt* this explanation. But perhaps it may not be amiss to briefly indicate at this point a few classes of facts that speak especially for evolution, and that seem to stand in the way of any other explanation:

1. The plasticity of species under domestication, and
2. The intergradation of species in nature.

Both these phenomena are well enough known to every observing person and each shows that species are not fixed

and immutable. The individuals of a species may, therefore, be arranged in a series with its extremes having very different appearance, and the differences between them may sometimes be correlated with their geographic distribution, and sometimes not.

3. The close adherence to structural type in the members of a single group that is modified for great diversity of habit and environment; and, conversely,

4. The superficial similarity wrought in different structural types, when they are modified to a common mode of existence.

5. Correlations of structure; when one part of any type is modified for a different sort of life, other parts are modified in harmony therewith. The foot, *a*, of figure 107 is never associated with the beak, *b*, or with any other beak in the series, except with beak of the type *a*. This is the sort of concordance that makes the interpretations of fossil fragments possible.

6. Vestigial structures; why should these exist at all, except they be ancestral?

7. The tendency of all embryos to recapitulate group characters. Why should such a tendency exist, but for age-long heredity?

The palæontologic record is exceedingly fragmentary, and especially lacking in the more simple forms, that would be most significant to us. The phylogenetic record is broken by the absence of connecting forms between the groups, existing organisms being only the twigs of branches, and often widely separated. The ontogenetic record is perverted by marked departures from the original course of development. But, notwithstanding these difficulties, which are so great as to make it easy to err in the interpretation of nature's genealogies, the evidence of descent is thoroughly convincing.

It is the more so because of the way in which each of the partial records supplements and corroborates the others, and it is certainly significant that the developmental lines traceable backward through both ontogeny and phylogeny are all *convergent*. They point to a common origin in the remote past, and to " descent with modification."

Facts, such as have been before us in the preceding chapters have satisfied biologists generally that evolution has been the method of nature; but the theories that have been advanced in explanation of the processes whereby evolution has been wrought out, have not met with so general acceptance. Yet, if evolution has had a past, it will have a future; and that future is of importance to us, because it must include the destiny of all races, including our own. Nothing could be of more practical importance to us than that we should understand the conditions of evolutionary progress, especially if these conditions should prove amenable to our control.

Many explanations have been offered, and some of them appear in part really to explain. All of them are under scrutiny at the present time. Investigations are in progress to determine their validity. It is well to reserve judgment, but it is also well to know the main features of the current explanations; for such knowledge is part of the common intelligence. Some of the more important explanations will, therefore, be outlined briefly here and in the next chapter.

## I. Natural Selection

The first explanation to receive any general approval (or even to attract much notice) was that of Charles Darwin. He observed how breeders, by selecting and isolating new forms as they arise in domesticated animals and plants, are

able to establish new varieties or races. He saw them producing perfectly definite results; horses bred for draft or for speed; peas selected for color of flower or for palatability of seed, etc. And in his mind's eye he saw nature producing like results by the removal of the unfit and the preservation of those best suited to her conditions. So, he called the process natural selection.

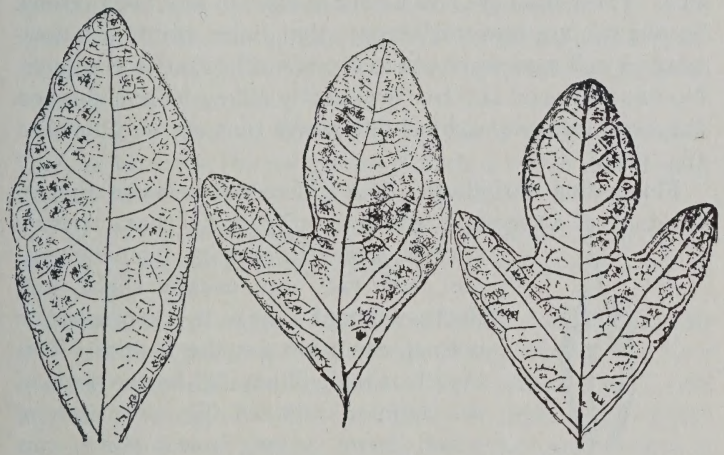


FIG. 117. Three sassafras leaves from the same tree.

The theory of natural selection is based on four facts: (1) Organisms vary; (2) In every species more young are produced than can possibly survive; (3) Offspring tend to resemble parents; and (4) There exists competition between the members of the earth's population.

Inheritance will be considered in the next chapter. Let us here examine the other three classes of facts severally.

**Variation.** — Animals and plants vary. No two persons look alike, nor do the individuals of any species, on suffi-

ciently close acquaintance. The careful shepherd knows his sheep as individuals, and it is only to the casual observer that they look alike. The robins on the lawn may be known personally by any one who will take the trouble to note personal characteristics.

Nature abounds in little refinements of structure, such as we see in the raised lines traversing the cuticle of our finger tips. These lines are never exactly alike in any two persons. So distinct are these differences that finger prints are nowadays a well recognized aid to the identification of criminals. No two leaves on any tree are exactly alike; indeed those on the same tree may exhibit differences that are very marked (fig. 117).

**Fluctuating variations.** The differences between the individuals of a species extend to every personal characteristic: stature, strength, activity, temperament, etc., but they are usually slight, and fluctuate about a mean that expresses the normal condition for the species. This may be simply illustrated by the seeds of the common ragweed (fig. 118) each of which bears a long apical point, surrounded by a circle of short spines. The normal number of these spines appears to be six, but many seeds have five or seven of these spines, and a few have even smaller or greater numbers of them. A count of the spines on 100 seeds taken at random gives the following results:

FIG. 118. A six-spined seed of the ragweed.

| No. of spines | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| No. of times occurring | 1 | 3 | 6 | 10 | 20 | 29 | 20 | 10 | 1 |

If now the seeds of each class be arranged in columns, and a line be drawn joining the tops of the columns, that line will

be the curve of variation, a common means of expressing variations of this type.

The class containing the greatest number of seeds (called the *mode;* the six spined class in this case) may be regarded as representing the normal condition for the species. It will be observed that the variations from the normal are here a little more numerous on the side of fewer numbers of spines, but that the curve is nearly symmetrical. It is an approximation to the symmetrical mathematical curve representing the distribution of error. Chance variations fluctuate thus about the normal.

A count of the ray flowers of 315 heads of the bur marigold, gives, when the results are plotted, a curve that is very much askew:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. of ray flowers (classes) | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| No. times occurring (frequencies) | 2 | 3 | 8 | 19 | 52 | 221 | 9 | 0 | 1 |

**Mutations.** — Larger variations, when they affect a number of correlated characters, and when with self fertilization they are self maintaining (i. e., when they "breed true"), are known as *mutations*. That mutants establish a new grade of variations is evidenced by the fact that each mutation establishes a new normal, about which ordinary variations fluctuate.

Mutations appear more rarely, and under conditions that are not at present understood. Their importance as starting points in the development of new races of plants and animals is well recognized by breeders. The long and careful pioneer study of them by Hugo De Vries has made clear their probable importance as starting points in the evolution of new species. De Vries calls many of the mutants he has found "elementary species." Their significance will again be referred to in the chapter on inheritance.

**More young produced than can survive.** — The species of organisms differ extraordinarily in the number of young produced, but all agree in the tendency to increase in a geometric ratio. The offspring of a single parent may number millions, or may be but few; but in either case, if all survived to reproduce in like ratio, the earth would soon lack standing room for the progeny. In the edge of the pond a single female frog may lay 300 eggs on a spring morning, and she may repeat the performance in successive years. If half of the succeeding generations were females, and were at maturity equally prolific, and if all should survive to reproduce, a simple calculation would show that in a very few years we should have more bulk of frogs than of water in the pond. Three pairs of offspring in one hundred years is said to be the rate of reproduction of the African elephant — a rate phenomenally slow; yet even this is an increase of 200 % in a century — sufficient if maintained without any losses except from old age, to cover the earth with elephants.

It is by excess of births that nature provides for inevitable losses; and the excess is proportioned to the dangers to be encountered in the race of life. A single pike may lay upwards of 80,000 eggs each season, scattering them broadcast in shoal waters, where most of them early fall a prey to other fishes. When hatched, their ranks continue to be thinned, however, in a diminishing ratio, as they become larger and better able to take care of themselves. But if out of all these offspring there remains at maturity for every pair of old pike a single pair of young ones surviving to reproduce each season 80,000 potential offspring, this race of fishes is holding its own; the natural balance is maintained. More than two would disturb that balance. A sunfish that guards its eggs until hatched, need not produce so many of them. But every species, in order to avoid extinction, must produce

sufficient excess of offspring to make good the inevitable loss of life during immaturity, and the failures of adult life.

**Competition.** — For want of food, therefore, and often indeed for want of standing room, the vast majority of organisms born into the world are foredoomed to perish before reaching maturity. Yet the method of nature is not more harsh than that we pursue in making a flower bed. For, do we not sow the seed thickly, to insure a good stand, and then thin out rigidly after germination? Among all organisms the vast majority of offspring are swept away by casualties against which they have no power to cope; by exposure to unwonted conditions, to floods, to drouth, to ruthless enemies, to diseases, etc. Here the elimination is wholesale and indiscriminate. But casualties are more or less local and occasional, and they always leave an excess of young to be eliminated by slower methods which allow some play for the powers or merits of the individual, and, therefore, some opportunity for competition.

**The struggle for existence.** — The thinning-out process inevitably goes forward, but, casualties aside, it is no longer wholly indiscriminate, for individuals vary. Some are better fitted than others to meet and cope with the perils and exigencies of life. If these be physical agencies, some are better able than others to withstand excess of heat or cold or drouth; if enemies, some are better fitted than others to combat, to escape or to elude; if competitors, some are stronger than others and better able to seize and appropriate to themselves the lion's share of the means of livelihood.

If we did not thin our seedling bed, nature would thin it for us by the slower, but not less certain methods of competition; and a few of the seedlings of stronger growth, reaching down more deeply with their roots to the food supply in the soil and spreading out their leaves more broadly

to the sunlight, would prove the better able to maintain themselves.

**The survival of the fittest.** — Herein lies the efficient principle of natural selection. *The fittest survive.* Not in the face of casualties; for these sweep out of existence good, bad and indifferent alike. Not in the face of insuperable difficulties; the best seeds may fall where there is not sufficient depth of earth; the best may have no chance of living. And not in times and situations of piping peace and plenty, when there is a living for all, and even weaklings may reach maturity. But, casualties and disasters of station aside, and given a stress of competition keen enough to call into requisition all the powers an individual may possess, the fittest survive. They survive to perpetuate their powers in their descendents. This means evolution.

**Fitness.** — Fitness for natural selection consists in two things:

(1) Ability to get a living and to reach maturity; this is provision for individual needs.

(2) Ability to leave well equipped descendents possessed of like good qualities. This is provision for the future of the race.

It is not, therefore, the superior excellence of a particular organ, but the balanced excellence of the organism as a whole that is of determinative value. Good leg muscles doubtless make for speed; but speed alone will not avail the hunted hare, if it have not also endurance and instincts of self preservation. " The race is not always to the swift." And all these will be of no moment whatever from the point of view of evolution if it leave no well-born descendents. For the sterile variety " carries its own death warrant." What has a chance of survival, therefore, under the most rigid natural selection, will depend on what variation of the

several parts of the body appear, and in what combination.

**Artificial selection.** — Man selects the variants he finds among his cultivated species of animals and plants, not for the good of the species, but for his own advantage. He selects corn for the starch or for the protein content of the seeds. He selects cattle for beef or for milk production. He selects fowls for egg production or for rapidity of growth, or for form of comb and wattles (fig. 119) or for color or sheen of plumage or for feathers or spurs on the feet; and pigeons and gold fish he selects mainly for qualities that suit his fancy. In the variability of living organisms he finds these resources valuable.

But his improved varieties are all weaklings, incapable of maintaining themselves in competition with the wild races from which they are derived, and requiring to be isolated and cared for, in order that the values for which they are selected may be realized. High-bred race horses are short-lived, of nervous temperament and of weak constitution. A

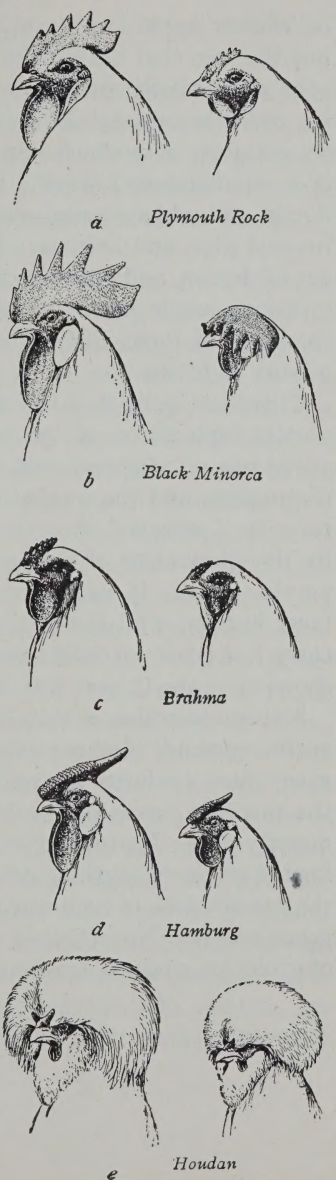



FIG. 119. Standard varieties of chickens (after Rice).

belleflower apple is a beautiful, fragrant and luscious fruit, but the tree that bears it is quite incapable of entering into open competition with the worthless wild crab apple. Nothing could be more striking in illustration of this point than the certainty with which wild species crowd out the cultivated ones on abandoned farms. Lop-eared rabbits, and flightless ducks, and udder-encumbered cows, and small-boned, small-brained pigs, and hairless, witless, barkless and tailless dogs are all freaks, and nature will have none of them. Her own creations, while often far more curious and extraordinary than any of these, differ from them all in the one essential quality of fitness.

This then, in brief, is the doctrine of natural selection, as a partial explanation of the process of evolution. Heritable variations of whatever sort or origin, furnish the materials of progress, and the competition of life, when of eliminative severity, " selects " the fittest variants for survival, chiefly by the elimination of the less fit. Real selection involves a psychic factor; it may occur if, for example, birds select the most luscious wild cherries or other fruit, whose seeds they carry to a place favorable for growth; or if insects select the showiest of the flowers whose pollen they distribute.

Natural selection is thus seen to be an explanation of the *modus operandi* of those extrinsic forces that tend to make every race conform to conditions of environment. With the intrinsic forces of the living organism, it can only indirectly deal. Natural selection does not, therefore, account for the origin of anything new among organisms, but only for the preservation of such new things as are heritable, advantageous and fit. Nevertheless, it is at this day the one process of evolution whose operations are clearly set forth.

## II. Orthogenesis

By this name we designate a racial tendency toward some one particular line of development: an innate tendency, uncontrolled by external conditions. Such racial development is not fortuitous, but in a single direction, straight ahead, as the name indicates. But orthogenesis is not an explanation of a process; it is merely a name for one.

The orthogenetic tendency is manifest in its incipiency when a group of organisms tends to vary strongly in the direction of some one particular structural type; when the variations are not promiscuous (indeterminate) but show a strongly marked trend. This is illustrated by the inherent odd-pinnateness of the compound leaves of the sumacs; and equally well by the inherent abrupt-pinnateness of the leaves of the cassias (partridge pea, etc.). It is best illustrated by the actual history of races as revealed by the long records of palæontology. Many definite lines of specialization, manifestly independent of environing conditions, are traceable among fossils, and some of these lines of specialization may be followed out to their final end. Useful structures, such as in their beginnings natural selection might have favored, have been developed far beyond their optimum, and their possessors have disappeared from the earth. Famous examples are the saber-toothed tigers and the Irish elk. The canine teeth of the saber-toothed tiger were so overdeveloped as to be useless, their tips projecting outside the mouth when opened; and the antlers of the Irish elk attained such size and weight as to be a very great encumbrance. Well developed canine teeth are manifestly advantageous for tearing prey, and all carnivorous mammals have them; and strong horns for meeting rivals in combat, are advantageous too, and the males of most social ruminants

have them; but in both cases the good thing was overdone; specialization far outran utility.

We need not go so far afield for illustrations of developmental tendencies that have exceeded utilitarian demands. What possible use is there for all the complicated apparatus of the milkweed or the orchis flower? or for all the arching, scalloping, and fringing of the lips of a mint flower? Clearly the living substance has inherent powers that manifest themselves in racial tendencies, independently of outward molding forces, and that sometimes are not amenable thereto.

We may perhaps conceive of orthogenesis as a manifestation of a sort of developmental inertia. A genetic tendency, once set going, tends to keep going in a straight line. How it starts we do not know. Natural selection may have something to do with its survival in the beginning, but evidently cannot stop it at the point of optimum development, for we must always remember that there can be no selection of single characters; it is individuals that are selected, with whatever combination of characters they may happen to be endowed. If the fittest Irish elk had ever antlers of increasing size, the only possible curb to antler development would lie in the extermination of the line. Natural selection can affect an organ only when that organ causes such manifest unfitness in the organism as is incompatible with the conditions of racial existence.

The phenomena of orthogenesis indicate that the springs of genetic progress lie very deep and that we must look for the origin of species in the origin of variations and of developmental tendencies. This matter will be considered a little further in the next chapter.

## III. Segregation

The breeder of plants or of animals isolates his choice varieties (except when propagated asexually) in order to obviate the retrogression that would inevitably result from intercrossing with inferior varieties. Biparental reproduction necessitates this. Nature also segregates her new forms more or less rigidly, and by a great variety of means, among which may be mentioned both external and internal agencies.

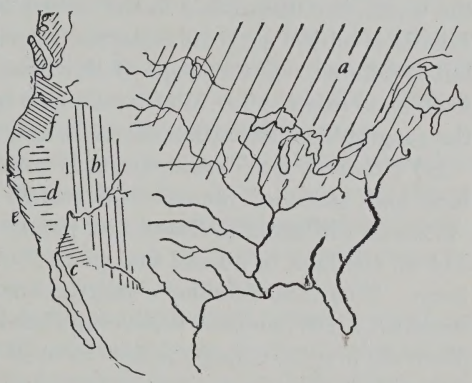



Fig. 120. Diagram of the distribution of the common song sparrows of North America. Shaded areas indicate the range, *a*, of the eastern song sparrow; *b*, of the Rocky Mountain song sparrow; *c*, of the gray song sparrow; *d*, of Samuel's song sparrow; *e*, of Heermann's song sparrow; *f*, of the Oregon song sparrow, and *g*, of the rusty song sparrow.

(1) *Geographic barriers.* — Two closely allied species, whose differentiation from one another may have been comparatively recent, are often found on opposite sides of a mountain chain or desert, or other impassable barrier. Thus, most of the fishes found on the two sides of the Isthmus of Panama are represented by two closely allied species, one on one side and the other on the other side. This is held to confirm the opinion of geologists, that the two oceans were once connected across the isthmus by open sea, the assumption being that time enough has elapsed since the emergence of the Isthmus, closing the passage, for the differentiation of the species from each other and from the common original stock.

This is segregation of the most obvious sort. Many a wide ranging species has varieties or sub-species for every distinct faunal area within its range. The accompanying map illustrates the geographic distribution of the races of the common song sparrow.

Whatever the means employed, nature has practiced segregation on a large scale, even isolating more or less the larger groups of organisms — the palms in the tropics of the world, the marsupials in the Australian region, etc., etc. This is a subject of great biological interest and importance, but it falls outside the scope of this book, and therefore, the student is referred for fuller statement to general works on the geographic distribution of plants and animals.

(2) *Climatic and meteorological conditions.* — Temperature and altitude, rainfall and winds, and other similar influences differentiate desert and plain, meadow and forest, and all the host of animal and plant forms that accompany them. This is so familiar a matter, that any one who has travelled a few hundred miles from home should be able to illustrate it by recalling the new form of animals and plants met with in the new environments visited.

(3) **Physiographic barriers.** — We often find two closely allied species in one locality inhabiting haunts that are just a little different. Insects and snails in the brook differ from those in the pond in the same locality: bog moss in water with acid reaction, and stoneworts in water nearby that is alkaline, etc.

(4) A species might become segregated into two groups, if among its members there should arise marked differences as to the *date of the breeding season.* Those maturing early could only mate with others of like early development, and would thus be segregated (permanently, if this seasonal habit were heritable) from those that mature late. Differ-

ences like this would be likely to be correlated with other differences, and thus two races might begin to diverge.

(5) A species might be segregated into two, if two of its groups of variants should be *mutually sterile*. Such variants occur among cultivated species.

(6) Two races may be developed out of one species when the variants fall apart in two groups, keep together in these groups, develop a "race feeling," and *refuse to interbreed*. This is reported to have occurred not infrequently when considerable numbers of deer have been kept in private parks. "Birds of a feather flock together," even when the feather is distinctive only of a race or a sub-species. This is the kind of segregation known as *preferential mating*.

These are the principal means whereby nature keeps her creatures apart in separate strains, or in groups of higher rank; far apart if the barriers be external agencies of isolation, but still apart even though near together, if there be such internal agencies as prevent intercrossing.

**The interaction of external and internal forces.** — So there have been and are still two main types of explanation of the process of evolution, typified by natural selection and orthogenesis; the one emphasizing outward conditions, the other, inner tendencies. The contemplation of the environment, and of the fitness of organisms thereto, leads to the overemphasis of adaptation; the study of the spontaneous and automatic activities of the living substance, tends toward confidence in their sufficiency. The two have much too often been treated as though they were mutually exclusive.

Direct adaptation seems especially to explain such classes of facts as are furnished by geographic distribution, especially of island life, by parallelisms, by mimicry, by degeneration, etc. Let us illustrate by means of the parallelism of the swift

and the swallow. How have these birds that are so different structurally, become so very much alike in form, in flight, and in foraging habits that it requires something of an ornithologist to distinguish between them? It is a peculiar field for bird life that they occupy. Above the ponds and lakes there hovers a teeming population of midges and other little insects excellent for food. How have these two, of all the groups of birds, become so finely and so similarly fitted to profit by it? Is it more likely that internal forces automatically produced such external likeness built upon persistent structural unlikeness, or that a common environment, imposing common conditions, has, acting through long ages, shaped to common form and function those parts with which it came most directly in contact? When we note the numerous details of similarity that are coupled with convincing evidence of diverse origin, we incline to doubt that these likenesses can be wholly due to internal spontaneous developmental tendencies, just as we doubt the originality of two essays that show many points of correspondence. Surely internal forces would modify internal form, as well as external. The impress of environment appears in this: that it is the outside of organisms that show all the special fitnesses to the environing conditions. As a distinguished American zoölogist has graphically stated it, " The inside of an animal shows what it is; the outside shows where it has been."

Nature has set bounds to which all the living must conform. This is seen not alone in externals of form, but also in the very fundamentals of organization. Even the types of animal symmetry correspond to environment. Of the three main types, spherical symmetry, like that of volvox (symmetry about a point) prevails where uniform conditions exist on all sides of an organism; radial symmetry like that of hydra and most plants (symmetry about a line)

prevails when conditions are alike at the sides of the axis of the body but differ at the two ends; and bilateral symmetry like that of the higher animals (symmetry about a plane), prevails when conditions are alike upon two sides but different above and below as well as before and behind, as they must be in all organisms that habitually travel over the surface of solids.

On the other hand, there are phenomena of divergent development, of the persistence of types through the vicissitudes of all environmental changes, of grotesqueries of form, and superfluities of structure and ornamentation, that speak most strongly for the dominance of the inner forces of life, and that negative or minimize external influences.

But it is not wise to exclude the possible action of either inward or outward forces in development when we know that both are ever present. The sightless condition of the fishes that live in the underground streams of caves in total darkness has often been treated as though it were a case of pure adaptation. But when we note that other fishes belonging to the same family (Amblyopsidæ) have weak eyes and incline to stay in the deeper shadows of the shores, we see that a racial tendency toward this sort of development may have favored the adaptation. Nature may have segregated the fishes best suited to cave life in the environment best suited to them, and then may have gone on perfecting the adaptation. Inherent tendencies and environmental influences are ever present, and development can only be the resultant of their interaction.

## CHAPTER VII

# INHERITANCE

Nothing is more familiar than the close adherence of offspring to the specific type of their ancestry. Although variations abound, they occur within very narrow limits. The egg of a frog can produce only a frog; never a newt, or a salamander. A hen sitting on duck's eggs can never avail to hatch anything but ducklings out of them; for there is nothing else in them. Moreover, our confident expectation that offspring will resemble not only their race, but their individual ancestors as well, is expressed by the proverb, "Like father, like son."

Heredity and variation are two aspects of evolution as viewed from the standpoint of the present, heredity looking toward the past, and variation toward the future. But whether a valuable variation counts for anything or not in racial development depends, as we have seen, upon whether it is heritable or not. Hence we must ask, whether able to answer or not, what is the nature of the bond between the generations?

## I. The Visible Mechanism of Heredity

The process of reproduction is one of the chief distinguishing phenomena of living things. We have in the preceding pages considered numerous remarkable structures and developments connected with it. But to distinguish its essentials we must now retrace our steps and consider again the simpler organisms. Yolk accumulation, embryonic mem-

branes, milk glands, etc., are mere accessories. Even the primitive vertebrates lack them all. Many animals have only eggs and sperms, and often merely scatter these free in the water, to develop without further parental contact or influence. And when we reach the simplest organisms, in some of them we find not even sex cells but only protoplasm; yet there appears to be faithful reproduction of parental characters; and again we are impressed with the fact that the primary functions of life are functions of protoplasm.

In Chapter II we sketched the phylogenetic origin of separate germ cells. Let us now note certain fundamental likenesses and differences of development with them and without them. First, there is continuity of living substance in either case. A part of the old lives on in the new. The protoplasm out of which new organisms are formed is potentially immortal.

Secondly, reproduction is, to a greater or less extent, a new production in either case. Even the two daughter cells of a protozoan are not merely halves of a divided mother cell; for the mate-

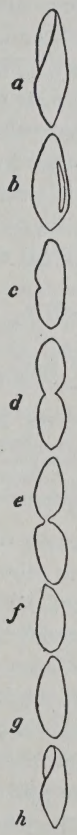



FIG. 121. Diagram of the division of a paramœcium (after Jennings). *a* and *b* show loss of specific characters; *c*, *d* and *e* show division; *f*, *g*, and *h* show re-formation of one of the daughter cells.

rials of that cell have been reformed with more or less of change. The unicellular organism undergoes regressive change before division takes place; the specific characters are lost, to be refashioned during the adolescence of the new cell (fig. 121). The process has been aptly likened by analogy to the dissolving of a crystal in its mother liquor, to be subsequently recrystallized out of it.

On the other hand there are very considerable differences, accompanying development by means of germ cells. These alone have descendents living on in successive generations. Being protected within the body of a multicellular organism

FIG. 122. Diagram of the relation between germ plasm and body plasm. *s*, body plasm (soma), egg and sperm shown below, and zygote (circle inclosing dot) beyond; *s*, *s*, *s*, the line of succession, three persons; father, son and grandson. *t*, the line of descent, the germ plasm, of which persons are the conservators.

and having no nutritive functions to perform, they are removed from direct contact with environment, and remain unspecialized with reference thereto. The germ cells are developed from the egg along with the body cells, but are set apart therefrom, sooner or later in the course of differentiation. Soon the body cells invest the germ cells with a covering in which they are sheltered and nourished during all their subsequent development. This general relation between germ plasm and body plasm is diagrammatically set forth in figure 122 in which *s*, *s*, *s*, represents the line of succession, and *t*, the line of descent.

It may well be, therefore, that parent and offspring resemble each other because both are developed from the same stock of germ plasm.

Every organism begins life as a single cell. It behooves us, therefore, to look a little more closely into the structure of that cell. Since the fertilized egg may develop into the complete individual without further parental influence, that new individual must be potentially present, and also the mechanism whereby its parts are wrought out. To the egg cell let us go, therefore, to learn further of the nature of this mechanism. Our task will be easier if we examine the minute transparent, nearly yolkless eggs of such simple marine organisms as sea urchins and starfishes, which if placed alive in sea water under the microscope will go on developing, the divisions succeeding each other in quick succession before our eyes. Nothing could be more convincing of the wonderful refinement of structure of the living substance, or of the precision of its processes, than to watch the behavior of the nucleus in a segmenting egg. And if we supplement what we can see in life by an examination of eggs that have been fixed at different stages, and stained by the precise differential methods of histology, we may discover the chief phenomena of nuclear behavior that regularly recur at every cell division.

Figure 123 is a diagram of ordinary (indirect) cell division. In the resting stage preceding division (*a*) the nucleus, inclosed by a nuclear membrane is seen to contain an irregularly disposed darker substance (deeply stained in histological preparations) called *chromatin*. This is deposited in a network of excessively fine and almost invisible threads of a substance called *linin*. Besides these, the watery fluid in which these lie (" *nuclear sap* ") there is also present, more or less constantly, a rounded body, the *nucleolus*, different in character from chromatin, as shown by its staining reactions. Outside of the nucleus but lying close to it is a minute body, the *centrosome*.

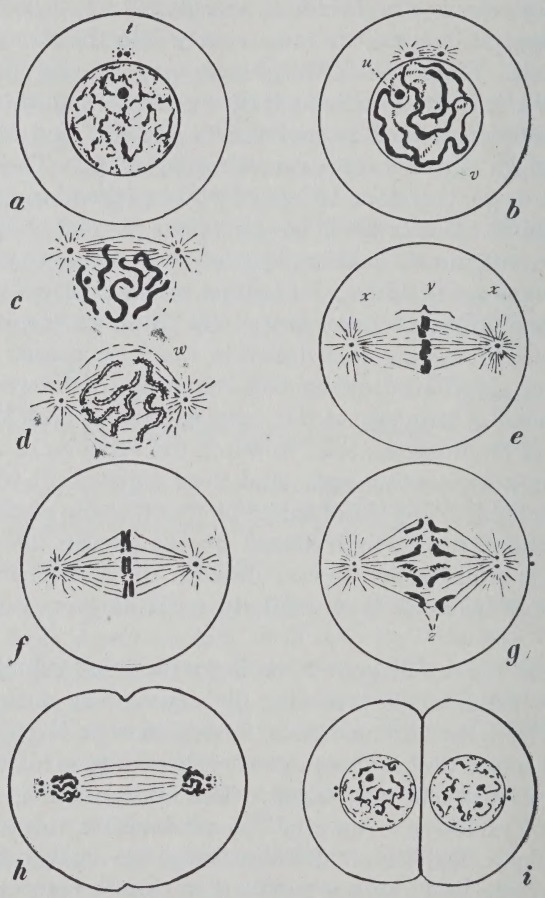



FIG. 123. Diagram of nuclear behavior in cell division (after Wilson). *a*, resting stage between divisions; *b*, beginning of division phenomena; *c* and *d*, formation of nuclear spindle and fragmentation and splitting of chromosomes; *e* to *i*, later stages: *t*, centrosomes; *u*, nucleolus; *v*, spireme; *w*, chromosomes; *x*, *x*, asters: *y*, chromosomes in equatorial plate; *z*, chromosomes separating.

The first sign of division appears in the division of the centrosome; the resulting daughter centrosomes move apart along the outside of the nuclear wall. The chromatin inside that wall begins to be gathered together in a long convoluted skein called the *spireme* (*b*). Before the centrosomes reach opposite sides of the nucleus, the nuclear wall begins to be dissolved. The linin threads take up a position stretched between the two centrosomes and so form the *nuclear spindle*. Corresponding linin threads in the cytoplasm become radiately arranged about the centrosomes to form the two *asters*. The chromatin of the spireme becomes broken into segments, that are shifted to the middle of the spindle, as soon as the spindle is fully formed. These are called *chromosomes*. This completes the first phase (*prophase*) of division.

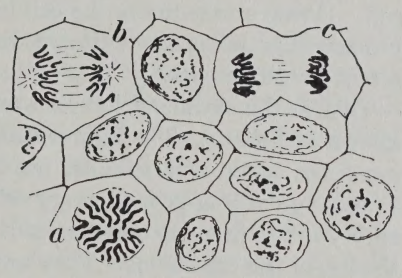



FIG. 124. Cell division in growing tissue (salamander epidermis). A number of resting nuclei, and three in process of dividing. *a*, spireme; *b*, anaphase of division, and *c*, late anaphase.

Then the chromosomes that have split lengthwise, each into two equal parts, move apart in halves along the lines of the spindle in two equivalent groups. The centrosome also divides. This is the second phase (*metaphase*) and climax of cell division. Now there is provided the nuclear material for two daughter cells.

The two succeeding phases are the reverse of the first two phases.

The chromosomes move in the next phase (*anaphase*) of division to the ends of the spindle, and form two compact groups, which tend to coalesce more or less into a spireme,

and a nuclear wall begins to be developed about them and the spindle begins to disappear. Finally, (*telophase* of division) the chromatin becomes scattered again upon the finer mesh work of the dispersed linin threads, the cell body divides, and the resting stage with which we began, is resumed.

The outcome of these processes is that each daughter nucleus receives half of the nuclear material of the mother cell. However unequally the cell body may be divided, this process guarantees an equitable distribution of the chromosomes in cell descent.

This is the ordinary indirect process of nuclear division known as *mitosis*. The figures successively formed by chromosomes, aster and spindle, are known as *mitotic figures*. These regularly appear at every cell division, not only in the embryo, but in every growing part of the body, throughout the life of the organisms. They are freely exposed to view in living transparent eggs, but in any developing tissue properly sectioned and stained, nuclei may be seen in some of the division phases above outlined (fig. 124). These phases follow one another in an inviolable order; each stage conditions the one that is to follow it; and together they seem admirably fitted for the equivalent distribution of those parts of the nucleus which appear most constant; that is to say, the chromosomes.

Chromosomes show significant features. Between spireme and spireme, they appear and reappear in like number and in similar form. The number differs in different groups but it is constant and characteristic for all the individuals of any given species, in all the cells of the body. The number varies from 2 in a species of round worm (Ascaris) to 168 in the crustacean Artemia, ranging in most cases between 12 and 36. The number appears to be a family characteristic

in the grasshoppers, it being 23 in the shorthorned grasshoppers and 33 in the meadow grasshoppers.

Chromosomes exhibit marked individuality of form, differing in different organisms in length, breadth, curvature, etc., but in a given species, they are fairly constant in form by pairs. In certain genera it is claimed that two species may be distinguished as well by the chromosome complex of a single cell as by the external characters of the adult animal.

**The history of the germ cells.** — Since at the beginning of embryonic life, the fertilized egg is already a new organism, charged with the potentiality to develop all the characters of the adult, we must seek the source of these characters farther back. How does the egg come into being?

It traces its lineage from an antecedent egg, as we have already seen (fig. 122). That antecedent egg gives rise to both body-plasm and germ-plasm, but the latter is very early set apart from, although surrounded by the former; walls are built up about the germ plasm (spermary or ovary walls), by which it is protected and through which it is nourished. Thus, the germ plasm is removed from direct contact with environment, and also from direct relations with the functional cells of the body, and in this isolation it develops.

The primordial germ cells, thus segregated, pass through a period of rapid divisions which succeed each other in quick succession without much intervening growth, and the result of which is great increase in numbers and great reduction in size. The small germ cells thus produced are called *spermatogones* or *oögones*, according as they develop in spermary or ovary. Then follows a growth period, without division, in which the normal size is regained, and much new cytoplasm is formed. The differentiation of the cytoplasm into the different materials that will subsequently be devoted to

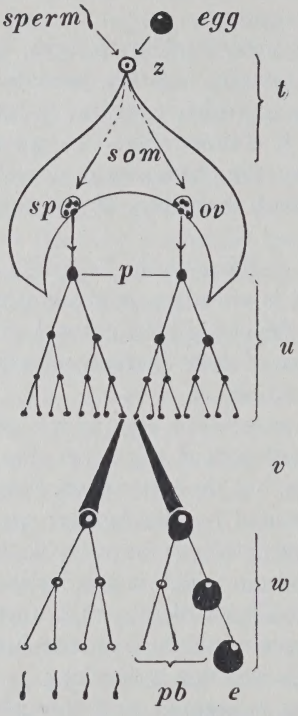



FIG. 125. Diagram of the derivation of the sex cells (after Boveri). *z*, the fertilized egg (zygote); *som*, the body plasm (soma); *t*, the developmental period during which the germ plasm and the body plasm are indistinguishable; *sp*, spermary; *ov*, ovary; *p*, primordial germ cells; *u*, the period of rapid increase in number and diminution in size (the number of divisions is much greater than shown); *v*, the period of increase in size with differentiation of cytoplasm; *w*, the two maturation divisions; *pb*, polar bodies; *e*, egg.

the production of different parts of the embryo occurs during this period.

**Synapsis.** — At the beginning of the growth period there occurs a fusion of the chromosomes within the nucleus in pairs, apparently with like paternal and maternal elements in each pair (these elements having, since the preceding fertilization, maintained themselves apart, although in one nucleus). This fusion is called *synapsis*. It brings into more intimate association the equivalent paternal and maternal units. Then follows a period of maturation of the sex cells, which involves two successive divisions only, and during which the germ cells are known as *spermatocytes* or *oöcytes*. The four cells resulting from these two divisions become the sex cells, eggs or sperms, but there is one marked difference, indicated in the accompanying diagram (fig. 125). In the case of spermatocytes, the divisions are equal, and four

sperms result; but in the case of the oöcytes, the divisions while equal with respect to nuclear parts, are very unequal with respect to cytoplasm, one cell retaining nearly all of it, the others being cast out from it as the so-called *polar bodies;* therefore, but one functional and perfect egg results.

One may easily see polar bodies in the newly laid eggs of pond snails — one or two or three very minute spheres according to the progress of oöcyte formation — lying close against the surface of the large egg, within the gelatinous envelope.[1]

Such are the form changes undergone by the germ cells during their development, among the higher animals in which they have been most carefully studied.

Many of the primary germ cells remain undeveloped through the life of the individual organism, and in most organisms they develop in cycles, corresponding to breeding periods. Division, growth and maturation may be found side by side in a single reproductive organ.

**Fertilization and maturation.** — The existence of sperm cells has been known ever since the great pioneer Dutch naturalist Leeuwenhoek and his pupils with home made lenses found them in the seminal fluid of animals, but they were long regarded as "wild animalcules." In 1875, Oscar Hertwig established the fact that fertilization consists in the union of one egg and one sperm only, showing that in sexual reproduction each parent contributes one cell of its own body to the formation of the young. Then it became evident that the sexes play an equal, although not necessarily an identical rôle, in hereditary transmission.

[1] Pond snails if brought indoors in winter and given a leaf of lettuce for food will usually begin laying in a day or two, and their large transparent gelatinous egg clumps are then easily obtained. These may be observed directly with the microscope as living material.

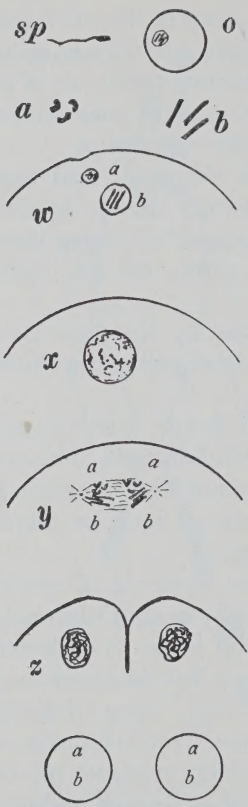



FIG. 126. Diagram of the separate maintenance of paternal and maternal chromosomes as seen in certain hybrids. *sp*, sperm; *o*, egg; *a*, the form of the chromosomes of the sperm; *b*, the form of the chromosomes of the egg; *w*, fertilization about to take place; *x*, the nucleus in its succeeding resting stage; *y*, the reappearance and grouping of the two sorts of chromosomes at a subsequent division; *z*, division of the cytoplasm. The condition in each nucleus is diagrammatically indicated by the circles below.

This conclusion was strongly re-enforced by the important discovery of Van Beneden (1883), that germ cells contain but half the number of chromosomes that is normal to the body cells of their own species. It became evident, therefore, that reduction and fertilization are complemental processes, the one leaving each sex cell with but a half stock of chromosomes, the other restoring to the fertilized egg cell the normal number. At the same time, the sperm introduces new elements into the lineage of the cell; the new organism must differ in composition from the old.

Every organism, therefore, that is developed from a fertilized egg sets out in life with a material endowment that is derived from two antecedent cells. In its nuclear equipment there are two sets of chromosomes. By the precise mitotic method, the substance of both paternal and maternal chromosomes (fig. 126) seems to be equally divided and distributed at every cell division. We can see that this is so, when paternal and maternal chromosomes are visibly different in form, as is notably the case in certain species that may be hybridized; for in the hybrid

embryos two sorts of chromosomes reappear, constant in number and form and grouped by themselves, in successive cell divisions.

**Chromosomes.** — That chromosomes play an important rôle in cell division is sufficiently obvious; mitosis might well have for its object the equitable division of them

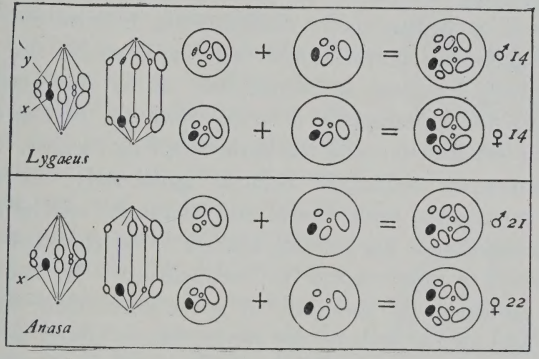



FIG. 127. Diagram illustrating the behavior of the sex chromosome in fertilization (after Wilson). For the sake of clearness, but four other chromosomes are shown, and these four diagrammatically; *x* is solid black.

among the descendent cells. That their rôle in sexual reproduction is of paramount importance is indicated by their uniform and parallel behavior in egg and sperm while cytoplasmic parts are undergoing the greatest differentiation.

The chromosomes in a single nucleus differ in size and form. They have individuality. The inference that they are the bearers of segregated hereditary characters was first confirmed by the discovery of a particular chromosome that is associated with the determination of sex. This sex chromosome has been studied in the squash bug. In the body cells of the female there are 22 chromosomes; in the male, but 21. In the cells of females one chromosome exists un-

paired, all the others are joined in pairs. In the maturation of the sperm mother cells, a division that occurs without the previous splitting of chromosomes (the *reducing division*) leaves an odd chromosome in half the cells. The resultant sperm cells, odd and even in their chromosome complement, unite with the full-equipped egg cells, as indicated in the accompanying diagram, to produce new male or female organisms, according to the chromosome distribution.

This accessory chromosome (fig. 127), which the female zygote only receives, is sometimes, as in the plant bug (*Lygæus*) accompanied by a small mate (*y*, of the figure), which in fertilization only the male offspring receive.

Chromosome reduction occurs, apparently, in all the higher organisms, both plants and animals, but the attendant circumstances appear not always to be the same. It is everywhere a preliminary to fertilization. In the higher plants it occurs at the time of spore formation; and the spores and all the cells of the gametophyte phase, as well as eggs and sperms, contain half the number of chromosomes that are found in the cells of the sporophyte. Thus in plants reduction and fertilization are widely separated in point of time. Two divisions of the spore mother cell with only one splitting of the chromosomes, result in these cells issuing with the half number in each, just as in the egg and sperm mother cells of the higher animals. If *x* represent the number of chromosomes in the sex cells, these relations may be expressed by the formula:

The higher animals { sperm (x), egg (x) } Zygote (2x) The new individual (2x) { sperm (x), egg (x) }

The higher plants { sperm (x), egg (x) } Zygote, Sporophyte (2x) Spores (x) Gametophyte (x) { sperm (x), egg (x) }

**Differentiation in the cytoplasm of the egg.** — There is also definiteness of organization in the cytoplasm of the egg.

Conklin has shown that in the egg of the ascidian, Cynthia, there are three kinds of protoplasm that are quite different in their appearance and also in their destination in the tissues. (1) There is a clear protoplasm that will develop into the ectoderm; (2) there is a gray, yolk-filled protoplasm that will develop into endoderm, and (3) there is a yellow protoplasm that will develop into mesoderm. In figure 128 these are imperfectly delimited, the yellow protoplasm being diagrammatically indicated by the heavier stippling, and the gray by the intermediate stippling; *a* represents the egg half an hour after the entrance of the sperm cell, but before the first division; the yellow protoplasm has taken up its position in a crescent across one side of the egg, half of it being shown in the figure. The first cleavage plane (median plane of the body to be formed later) will be in the plane of the paper, dividing these substances symmetrically; *b* is a corresponding view in the 8-cell stage, with the polar bodies still persisting at the upper pole, and the yellow protoplasm occupying a part only of two cells of the lower hemisphere, while most of the gray protoplasm has withdrawn into the other two. The yellow protoplasm will all develop later into the early muscle segments lying alongside the notocord. Here we have definite predetermined materials for the making of the embryo, which, though differing in kind do not correspond with cell

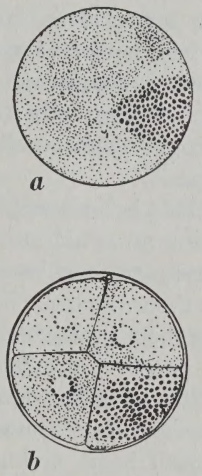



FIG. 128. Eggs of the ascidian Cynthia showing differentiation of organ forming substances in the cytoplasm, lateral views (after Conklin). *a*, unsegmented, but after fertilization; *b*, in the eighth-cell stage.

boundaries and which are, therefore, clearly unrelated as yet to chromosome behavior.

**Parthenogenesis.** — New individuals develop from eggs, but not from sperms alone. Yet eggs and sperms alike seem to have the necessary nuclear equipment for the complete develoment of new individuals. The eggs alone, have the cytoplasmic supplies necessary. In many large and widely separated groups of animals, (aphids and other insects, daphnids and other crustaceans, rotifers, etc.), there occurs habitually the development of eggs without fertilization. This is called *parthenogenesis* (*parthenos*, virgin, and genesis).

This is no rare phenomenon. If one will but carefully examine an aphid-infested geranium plant in his window or conservatory he will see that all the aphids present are females. If he then watch the doings of the mature aphids present he may see them giving birth to living young. If he take the trouble to isolate a new-born young one in a new place on the plant (lifting and transferring her gently on the soft tip of a feather) she will, if uninjured, feed there and grow, and in a few days herself begin giving birth to living young, no male having been present.

In the honey bee, all the drones are believed to be developed from unfertilized eggs.

This phenomenon is usually an accompaniment of peculiar conditions of life, and it alternates at longer or shorter intervals with true sexual reproduction.

In the vast majority of organisms, however, the addition of the sperm to the egg is a necessary stimulus that must be supplied before development proceeds. But the eggs of a number of animals that ordinarily require fertilization can be artificially stimulated to develop by temporary immersion in proper alkaline solutions.

**The sperm nucleus also totipotent.** — If an egg be deprived of its nucleus, the cytoplasm dies; it has no power to develop alone. But enucleated eggs have been fertilized and caused to develop by the experimental addition of sperm cells (fig. 207); the sperm cell enters as it would to fertilize the egg nucleus, but instead, takes the place of that nucleus, and then development proceeds. Evidently the necessary nuclear equipment for development is present in the sperm as well as in the egg, and is duplicated in the zygote in cross fertilization.

**Summary.** — The chief facts now before us, regarding the material basis for inheritance, are:

1. The continuity of the germ plasm through the generations.

2. The separateness of the germ plasm from the body plasm and from contact with environment.

3. The presence of chromosomes in the nucleus of every cell of the body, constant in number and form.

4. Cell increase with mitosis in body plasm and germ plasm alike, insuring equal division of the chromosomes between descendent cells.

5. Self perpetuating chromosomes, half of them traceable back to the germ cells of the father and half to those of the mother.

6. Their likeness in egg and sperm, while all other parts of the two cells are remarkably different.

7. Their persistence in pairs (allelomorphs), one member of each pair from each parent.

8. The reduction by half in number of chromosomes preliminary to fertilization.

9. The restoration of the number by fusion of sex cells in fertilization.

10. The conjugation or temporary coalescence of the mem-

bers of each pair in synapsis, previous to the reducing division.

## II. Mendelian Inheritance

It was known of old that vegetative increase of individuals proceeds with dependable uniformity, and that marked changes result from cross fertilization. The horticulturist maintains his choice varieties of fruits by rigid adherence to asexual methods of propagating them (cuttings, layers, stolons, buds, etc.), well knowing that cross fertilization will introduce new characters to modify (and from his point of view, to deteriorate) his commercially valuable strains. The breeder of domesticated animals has not this advantage. He can increase his flocks only by bisexual reproduction. Hence, he must isolate his pure bred individuals in order to maintain the purity of his stock. This is the key to the efficiency of isolation, as well in nature, as in plant or animal industry.

**Pure breeds and hybrids.** — In nature, the individuals of a species usually present great uniformity of appearance. They "breed true." But in some wild species there are diverse forms more or less constantly appearing. Species that have been long domesticated always show greater diversity, due to man's influence in selecting and isolating the most divergent types — especially such types as natural selection would ruthlessly eliminate.

This is the usual way of obtaining new forms. We cannot compel nature to produce anything; we can only wait upon her, and preserve our choice of what she offers, from the swamping effects of intercrossing and from the rigors of a harsh environment. When the breeder of plants or animals wishes to obtain a new strain, he breeds together forms that differ with respect to the characters of which he desires to

secure a modification. This is hybridization. If all the offspring of any given variety that is bred *inter se*, are alike in any given character, they may for all practical purposes be considered in respect to that character pure bred. What the result will be when any two varieties are crossed, what characters the offspring will bear, can only be determined by trial; it will always be the same between the same two pure varieties.

As to heritability of results, the offspring may be sterile, and therefore, self-annihilating. The best known example is the mule, a cross between the horse and the ass. There is no race of mules; other mules are to be obtained only by repeating the crossing of the parent species. Or, the hybrids may be relatively stable, and breed true, as single new-formed race from the beginning. The garden sunberry, a cross between two wild inedible species of Solanum, is said to be an example, and there are many others among cultivated plants. Or, they may be unstable, as in the great majority of cases.

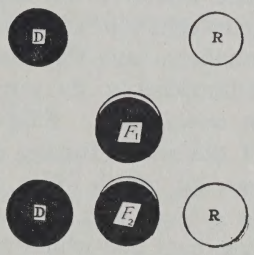



FIG. 129. Diagram of Mendelian inheritance. D, the dominant character R, the recessive $F_1$ and $F_2$, the first and second generation hybrids respectively.

**Alternative inheritance.** — When parental characters are preserved in the hybrids, unfixed and unaltered, we have alternative inheritance — the type that has hitherto received most attention, and which in its behavior seems to offer the most obvious parallel to the behavior of the chromosomes. The offspring of the first generation exhibit the characters of one parent or of the other; but when these hybrids are bred together, in their offspring the characters of both parents reappear. In the first generation hybrids one character appears

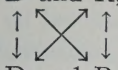
(is *dominant*), and the other disappears (is *latent* or *recessive*). Both characters are present, but both cannot appear at the same time; a flower cannot at the same time be fragrant and scentless. Both have been inherited, however, along with duplicate chromosomes, and in succeeding generations the parental characters will reappear. This type of behavior among hybrids was first studied carefully by Gregor Mendel, and is called Mendelian inheritance.

Mendel's great service lay in a long series of careful hybridizing experiments, from which the principle was deduced that whatever the appearance of the hybrid, it produces germ cells like those of its parents in approximately equal numbers, and the character of its own offspring will be determined by the way in which these germ cells are paired in fertilization. Suppose, for illustration, that D and R of the accompanying diagram (fig. 129) represent the two parents, which differ in one character only, that of color. D is black and R is white. Suppose also black to be the dominant and white the recessive color. Then the offspring in the first generation ($F^1$) will all be black. But if they be bred together, their offspring will be both black and white in the proportion of three black to one white. Then, if the whites be again bred together, all their offspring will be white. The white character which disappeared in the first hybrids, was obviously still present, and has been sorted out again. This relation between characters in the germ cells has been aptly compared to the putting together in pairs of pieces of glass of two kinds, one transparent, the other opaque; when placed together only the opaque one is visible, but when again separated, both are again apparent.

If, as Mendel supposed, the germ cells possessing the two characters separately, are present in equal numbers in the reproductive organs of the hybrids and are combined in pairs

according to the law of chance, there are but four possible combinations of them giving three classes, as indicated below:

D and R, germ cells of one hybrid parent



in chance combination with

D and R, germ cells of the other hybrid parent

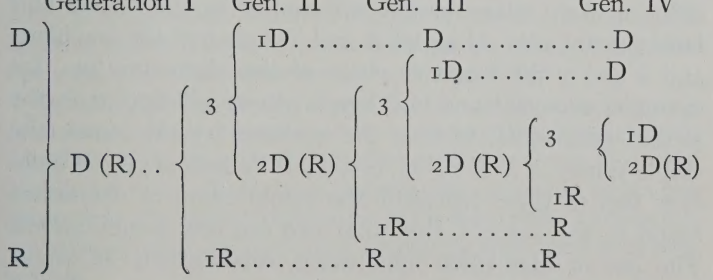
give in the second ($F_2$) generation, DD + 2DR + RR in the proportion, 3 black to 1 white.

Otherwise stated, if any two of these hybrids be bred together there result the following possible combinations of their characters in their offspring (the characters D and R of one parent being underscored in order to distinguish sources):

D and D, uniting, give D, a pure dominant
D and R, " " DR } hybrids } black
R and D, " " DR }
R and R, " " R, a pure recessive — white.

Of the black individuals it is obvious that there are two classes although all look alike; for one individual out of every three is, like the white, pure bred containing sex cells of one kind only, while the other two are still hybrid in character. The results of intercrossing of like with like in successive generations is indicated by the following table:

*Parents.* *Offspring, (mated like with like).*



Mendel's law assumes that the gametes bearing the characters of the two parents are produced in equal numbers, and distributed at pairing in accordance with the law of chance; and this assumption is not contradicted by the known facts. And since it offers a simple mathematical basis for calculating the results of a variety of crosses, it may readily be tested, as, for example, by backcrossing a hybrid with an individual of either parent stock. If mated with the recessive stock, the result should be as follows (given, of course, as for any test, a sufficient number of offspring):

D and R, germ cells of the hybrid parent

in chance combination with

R and R, germ cells of the recessive parent, give

2DR + 2RR — in the second ($F_2$) generation, *i. e.*, 50% of each color.

In the more typical cases of alternative inheritance, all the foregoing proportions have been substantially realized in breeding experiments.

When the parents differ in two or more characters, the hybrids bearing germ cells that bear all these characters severally, will effect new combinations of them, and forms differing from either parent will appear in the second and later generations. If we let *X* and *Y* represent the dominant and *x* and *y* the recessive phase of two characters (as, for example, eye color and hair length) there will appear in the second generation, besides the unstable hybrid forms, the stable forms *XXYY*, *XXyy*, *xxYY*, and *xxyy*. Whichever two of these represent the combination of characters found in the parents, the other two are new combinations. The law of Mendelian inheritance, substantially as estab-

lished by its founder, is represented in the accompanying table (after Castle).

| Number of Differences between Parents. | Visibly Different Classes, each containing one Pure Individual. | Total Classes, Pure and Hybrid. | Smallest Number of Offspring allowing one Individual to each Class. | |
|---|---|---|---|---|
| $n$ | $2^n$ | $3^n$ | $4^n$ | |
| 1 | 2 | 3 | 4 | Tested by Mendel for peas and found correct. |
| 2 | 4 | 9 | 16 | |
| 3 | 8 | 27 | 64 | |
| 4 | 16 | 81 | 256 | Calculated. |
| 5 | 32 | 243 | 1024 | |
| 6 | 64 | 729 | 4096 | |

Castle has proved by breeding experiments that in guinea-pigs length, pigmentation and roughness of coat are hair characters that are separately heritable, and that in crossing they follow fairly Mendel's law. And he summarizes his observations as follows:

"This experiment illustrates two important principles in heredity: First, if as regards the hair alone there exists such a variety of characters separately inheritable, how great must be the number of such characters in the body as a whole, and how remote the probability that any animal will in all characters resemble any individual ancestor, provided that in a considerable number of heritable characters a choice is offered between alternative conditions.

Secondly, the experiment shows how a variety of new organic forms may quickly be produced by cross-breeding, leading to the combination in one race of characters previously found separately in different races. Thus, in guinea-pigs, one can obtain within two generations any desired combination of the three pairs of alternative coat-characters, if one produces a sufficiently large number of individuals."

Obviously, without variation no new characters are obtained by such intercrossing, but merely new combinations of characters that previously existed apart. But when new characters appear among the variants of a species, and especially when a number of new characters appear simultaneously as in typical cases of *mutation*, then intercrossing may be the means of bringing these characters together in all sorts of combinations, some of which may be of value to man, and some of which may be *fit*, and may, therefore, furnish a basis for further natural evolution.

## Mendelian Inheritance and Chromosome Behavior

Mendel showed that in hybridization the characters of the two parents are separately inherited, and that even though certain of these characters (the *recessive*) may not appear in one generation, they persist and reappear with further interbreeding. The study of the germ cells has shown a mechanism that closely corresponds to this. Separately inherited characters and separately maintained chromosomes — that is the parallelism. *Chromosomes* separated at the maturing of the sex cells, and brought together again in a duplicate set in fertilization, provide a material basis for such chance combinations of parental characters as Mendel's results required.

The nuclear mechanism is one of amazing minuteness and delicacy. We cannot see heredity characters in the chromosomes. We can only infer their presence there.

**Genes.** — What we can see in chromosomes, even in the best of preparations and with the highest power of the microscope is only their size, shape and position and relations to each other in the cell nucleus. That is enough to be convincing of their individuality. They exist and continue in parallel

pairs, just as they come from the two parent germ cells at fertilization. They reappear, each with its own mate in its own place and likeness, at every cell division. But they are of baffling minuteness, and their constituent elements we cannot see at all.

The sex chromosome (**x**) was the first to be recognized and named. It was found to exist in cells of the body of females, and not in males. Therefore the two sex cells that contribute this chromosome in fertilization bring with it the determiners of femaleness. We may conceive of determiners of separately inheritable characters as the ultimate invisible structural units in chromosomes, and for them we may use the current term *genes*.

**Linkage.** — Femaleness is not expressed in a single character. It is manifest not only in sex organs, but also in peculiarities of body form and stature, and of voice and manner and instincts. The x chromosome must therefore carry the genes for all these characters, for they are inherited together. That is *linkage*. Since chromosomes are few, and separately heritable characters are many, linkage is to be expected in all the chromosomes. It has been shown by Morgan and others that the characters of Drosophila are linked in four sets that correspond to the four pairs of chromosomes in that fly.

Linkage is known in characters apart from sex. A classical example is that of the color of flower and shape of pollen grains in sweet peas. Purple blossoms and elongate pollen grains go together; likewise red blossoms and round pollen. Bateson and Punnett showed that these combinations are inherited like single characters in definite Mendelian ratios.

Linkage is a fairly constant and consistent phenomenon. Sex characters, for example, occur in regular association, but there are some exceptions (as, occasionally, a woman with a beard); and the study of the exceptions has furnished a basis

for theoretical explanations of the behavior of the genes in inheritance.

That the line-up of the genes in the chromosomes parallels the *ensemble* of characters in certain races of vinegar flies, seems to have been proved experimentally. Specific relations of particles in the visible chromosome complex accompany particular characters (in pigmentation, etc.) in the adult flies.

**Crossing over.** — In a very small percentage of cases a character of one linkage group makes its appearance in another group. The theoretical explanation of this is that at the conjugation of the paired chromosomes previous to maturation of the sex cells there occurred an exchange of material between the two members of one pair. These sometimes appear to be twisted about each other in synapsis, and at their separation, an exchange of genes might perhaps occur in the manner indicated in the accompanying diagram.

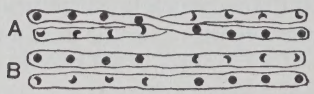



FIG. 130. Diagram of "crossing over" of the genes in a pair of chromosomes (one set being represented by circles and the other by crescents, *A*, at the time of fusion, and *B*, after their breaking apart.

On the probability that genes farthest apart in the chromosomes are most likely to become separated in crossing over, and on calculations based on actual occurrences of crossing over, highly theoretical chromosome maps have been made showing serial arrangements of the genes in them.

The classical material for studies of such phenomena is the little vinegar fly, Drosophila. This insect is favorable for study because it is easily reared, it breeds readily in captivity, it breeds throughout the year, it has a short life cycle with a new generation every few weeks, and its chromosomes are few in number and fairly well differentiated in form. It is therefore possible with this fly to make experimental breedings and to study the parallel behavior of bodily characteris-

tics of individuals and the form that the chromosomes take on in individuals of like sorts. Thus it is sought to trace the peculiarities of individuals back to their hypothetical sources in the chromosomes. That these are composed of genes, and that genes are the determiners of separately inheritable characteristics is the *particulate theory* of inheritance.

There is but one time when the paternal and maternal members of each pair of chromosomes appear to be fused together and that is in the synapsis which precedes the maturing of the sex cells. It is believed that when they separate again completely, after synapsis, regular and normal linkage of characters occurs, and the failure to separate in the normal way leads to abnormal development. Crossing over is but one of these departures from the normal. Two others may be cited.

When the two members of a chromosome pair altogether fail to separate after synapsis, that is called *nondisjunction.* The subsequent reducing division leaves one sex cell in possession of the coherent pair and the other lacking it altogether.

When only a part of one member of such a pair remains after synapsis attached to the other member, that is called *translocation.*

There is in our own day much interest in these phenomena and great activity in their study, both in chance occurrences and in aberrancies induced experimentally, by exposure of the developing germ cell to x-rays, and by other means. Much evidence has been accumulated indicating that in the chromosome complex are the potential determiners of personality.

CHAPTER VIII

# THE LIFE CYCLE

## I. The Normal Life Cycle

Among the simplest organisms, in which each cell may go on growing and dividing indefinitely, the familiar phenomena of youth, maturity, and old age, are not apparent. Every cell is a germ cell, and, therefore, ever young. But with sexual reproduction comes in the dual organism, composed of body plasm and germ plasm, only the latter continuing through successive generations.

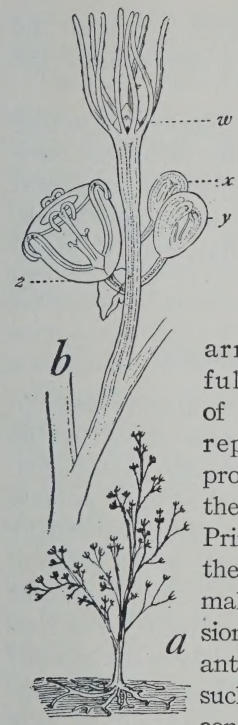
It is the common lot, among all organisms except the lowest, to be developed from an egg, to be supplied in infancy with food, to pass through hereditary changes of form, to grow and reach maturity, to exercise for a longer or shorter period the matured powers of the body, to produce offspring, and then to grow old and die. Youth, maturity, and age follow each other in an orderly progression that is readily definable in terms of metabolism, thus:

1. In youth the building up processes are in the ascendency. Assimilation is greater than dissimilation (*juvenescence*).

2. In maturity the waste and repair of the body are on a parity. Assimilation is equal to dissimilation.

3. In age the building up processes are in a state of relative decline. Assimilation is less than dissimilation (*senescence*).

Although we may thus state in metabolic terms the history of the body, the explanation therefor must be stated in terms of reproduction. It is necessary for the organism to




establish itself, before it can do much to provide for posterity; hence, the nutritive apparatus of the body is developed first, and growth precedes reproduction. The period of adult life may be long, as in elephants, or short, as in mayflies; it may be reached by a gradual and regular development, or by a series of abrupt form changes; but when it arrives with full maturity of powers, the reproductive process takes the ascendency. Primarily it is the period of making provision for descendants. Whether such provision consist merely in mating and depositing eggs, or whether in addition to this, the substance of the body be transformed into food for the young, or whether, still further, the physical powers of the body be devoted to the care of the young, or whether, finally, as in human society, with long years for individual activity, the labors of

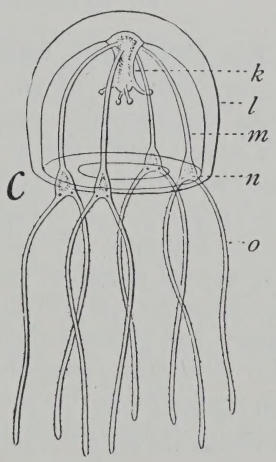



FIG. 131. The Colonial hydroid (*Bougainvillea*). *a*, the form of a small colony. *b*, a bit from the tip of one of the branches; *w*, tentacles of a single hydranth; *x*, *y*, *z*, stages in the development of the buds (medusæ). *c*, the fully formed and free swimming medusa (jelly fish); *k*, the body (manubrium) with the mouth at its tip; *l*, the surrounding bell; *m*, radial canal; *n*, sense organ; *o*, tentacle. (*b* and *c*, after Allman.)

life be devoted to securing gains for postering, it is all the same; the primary concern of adult life is provision for the future of the race.

The regularly progressive life cycle is sufficiently familiar and needs no further illustration. But this undergoes some remarkable changes, three of which will now be considered under the following headings: (1) Alternation of generations, (2) Special methods of asexual reproduction, and (3) Metamorphosis.

## II. Alternation of Generations

This phenomenon consists, as we have already seen, in the establishment of two segregated phases within the life cycle, one sexually, and the other asexually reproducing. We have already traced the development of it in gametophyte and sporophyte of the higher green plants. An equally good example of it is found among animals in the group of marine hydroids. Medusa and hydranth are there the sexual and asexual phases of the life cycle respectively. The free-swimming medusa (jelly fish, fig. 131, *c*) produces the eggs and sperms and liberates them in the sea. These after fertilization develop into sessile hydranths (fig. 131, *a* and *b*) (more or less similar to the common hydra), which in turn develop medusæ by various modes of asexual budding.

## III. Methods of Asexual Reproduction

Sexual reproduction without segregation tends toward reducing all the forms to a common level, but with segregation, whether external or internal, it is a potent means of effecting species change. Asexual reproduction is *quantitative* rather than qualitative increase. One individual is multi-

plied; the new ones growing up are separated parts of that one, and are therefore essentially like it.

The parts, however, are not necessarily identical with the parent, or with each other; when separated they may develop slight differences, as in the well known phenomenon of bud variation, and such differences may be increased artificially by selection. One branch of a rose bush may develop finer flowers than any other on the bush. Cuttings of this branch may be selected for growing, and the best-flowered shoots developing from these cuttings may be again selected with some advantage. But there is no probability that these improvements would be inherited.

The special means by which individuals multiply themselves asexually are far too numerous and diverse for us to attempt to consider them all here. Stools and stolons and runners and tubers and offsets and bulbs and a dozen kinds of detachable buds, are known to every student of plants. Indeed, many of those plants that have been able to advance into and conquer difficult environments and become dominant in them, (such as the pond-weeds on the bottom in shoal waters, and the grasses and sedges in the fire-swept prairies and marshes) increase mainly asexually, by extensions of the plant body. They still produce seeds, but they hold their ground by continuous and exclusive occupancy of it.

Budding and fragmentation and other such methods are common also among the lower animals. This we have observed in the hydra. But all such increase has to do with growth as well as with reproduction. Let us here consider some more specialized reproductive parts and methods, that are more exclusively adapted to reproductive ends.

**Asexual reproductive cells.** — When these are formed for dispersal, they are usually called spores. With ordinary spores, as they are commonly produced upon the aërial parts

of plants, we have already become acquainted (Chapter II). These are minute resting cells, usually invested with a protective covering that resists evaporation, and that permits of their being distributed by currents of air.

Among aquatic thallophytes, both algæ and fungi, there occurs at intervals a breaking up of the cell contents into minute motile naked unicellular reproductive bodies. These are called *zoöspores* or *swarm spores*. Each zoöspore acquires two or four flagella (or sometimes a circlet of cilia), and, escaping out of the old cell wall, it swims about in the water. Finding a suitable situation it attaches itself and begins to develop a new plant body like that of its parent.

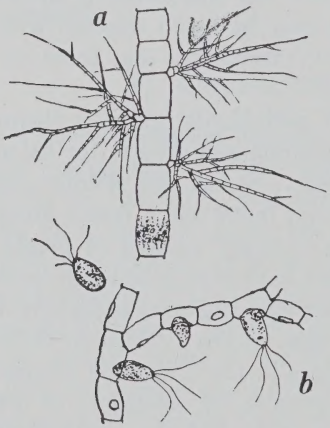



FIG. 132. Draparnaldia. *a*, a bit of the stem, with three branches; *b*, a bit of a branch that is yielding zoöspores.

The alga, Draparnaldia, shown in figure 132, which grows attached to stones in the riffles of small clear-flowing permanent streams, and is easily seen trailing its long beautifully branching filaments in the current, is a favorable one in which to observe zoöspore formation; for it will usually develop zoöspores a day or two after being brought out of its native environment into the laboratory. The spores, escaping from the cells singly, will swim to the lighted side of the containing vessel, from the surface of which they may often be obtained in great numbers.

It will be noticed that the figure of the zoöspore of Draparnaldia does not differ materially from that of certain of the

gametes we had before us in Chapter II. It seems probable that in the beginning sex cells were developed out of zoöspores. Both are present in certain algæ, and are hardly to be distinguished in form; and the differences between them almost vanish, when, as sometimes happens, the gametes develop without preliminary fusion in pairs.

**Multicellular reproductive bodies.** — In certain of the lower fresh water animals, notably in sponges and bryozoans, there are special multicellular reproductive bodies called *statoblasts* (also known as *winter buds*, and *gemmules*). These are like resting spores only in function, and in having resistant walls which tide them over the dry, hot season, when the shoal waters in which they grow evaporate. While they are often spoken of as seed-like bodies, they are wholly unlike seeds in that they contain no embryo, and they are entirely different in origin. During the growing season (spring and early summer) little groups of cells become segregated within the tissues of the parent animal (fig. 133, *k*), and become invested there with a common protective covering, the statoblast wall, that is often of remarkably complicated and beautiful structure. When the parent dies and its flesh disintegrates, the statoblasts are liberated, to be carried about with the waters, or blown about with the dust of the desiccated bottom mud, or, in the case of statoblasts provided

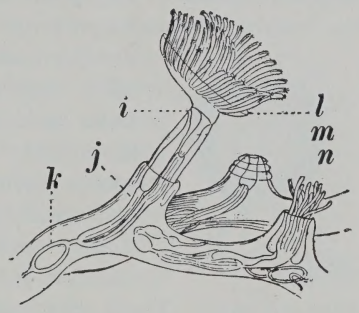



FIG. 133. Plumatella. A small part of a single branch, with three individuals in different states of contraction; *i*, anus; *j*, intestine (U-shaped); *k*, statoblast developing; *l*, lophopore (crest of tentacles); *m*, esophagus; *n*, the chitinous sheath that shelters an individual. (After Allman.)

with grappling hooks, such as those of Pectinatella (134), to be carried and distributed by aquatic animals. In the spring, those favorably situated germinate and develop new colonies of the parent form.

Statoblasts occur in the fresh-water groups of animals, most of whose members are marine. They are probably an adaptation of the life cycle to the conditions imposed by shoal and impermanent waters. Fresh-water sponges produce statoblasts in very great abundance. In early summer the freshly grown sponges may be found by lifting and overturning boards, boughs, or almost any solid support that projects into the water, and few, if any, statoblasts will be present; but in late summer when the sponge flesh is falling away, the statoblasts will be found in patches scattered thickly over the surface as minute rounded yellow bodies about the size of mustard seeds. These, after resting a spell, may be germinated in a watch glass. The numerous amœboid cells contained in them will issue separately from a side pore in the wall and come together to form a delicate chimney-like tube. This is the first of the water channels of the new sponge. Out of its summit the water can very early be seen streaming. Doubtless it is in this way that new sponges are started in the sloughs each spring. Many of them may remain attached to the support where they grew, there to develop a new sponge on the old site.

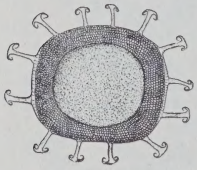


FIG. 134. A statoblast of the melon bryozoan, Pectinatella.

**Polyembryony.** — This is another very different kind of asexual method of increase. In certain parasitic insects of the order Hymenoptera, the eggs which are laid within the soft and richly nourished larvæ of other insects, undergo a division which is rather fragmentation, than segmentation;

for it results in the development not of a single embryo but of many embryos. The parts into which the nucleus divides develop separately as indicated diagrammatically in figure 190, each becoming a complete embryo, and growing later to adult estate.

A significant feature of development by this method is that all the individuals developed from one egg are of the same sex.

**Reproductive methods in general.** — Sufficient illustrations have now been before us to show that there is one sexual method of reproduction, fairly uniform and consistent throughout the organic world, but that there are many asexual methods, and that these latter are most diverse. The former is uniform in its fundamentals in all kinds of environment; the latter are uniform in nothing, being related to external conditions of life.

The unity of the organic world is hardly more manifest in the possession of protoplasm than in the production of gametes, and in the fusion of these in fertilization. The primary differentiation of multicellular bodies is into germ plasm and body plasm. This is even older than the differentiation between plants and animals.

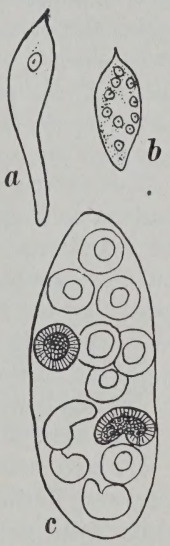



FIG. 135. Polyembryony in Polygnotus (after Marchal). *a*, the egg; *b*, the same after repeated divisions of its nucleus; *c*, the same after the development of separate embryos from each of the parts (details indicated diagrammatically in but two, and these at different stages of progress).

Secondary sexual characters show as great diversity as do asexual reproductive phenomena; these are the afterthoughts of sex: these are the special means adopted by special groups. How different are even spermaries and ovaries in the stoneworts and in the liverworts! How lacking in common fea-

tures are the reproductive organs of an earthworm and a salamander! All these have been more recently developed, along independent lines, in accordance with the tendencies and in adaptation to the needs of the different groups in which they are found. Only the all-essential germ cells remain alike.

## IV. Metamorphosis

This is the name applied to changes of form that are undergone after hatching from the egg. Such changes may be inconsiderable, as in the slowly-developing earthworm, but in a number of the higher groups of animals they are so great that the young of many forms were originally described as independent organisms, and given separate names. Thus arose the names still borne by the nauplius and zoëa stages of post-embryonic development in crabs, the leptocephalus stage of eels, etc.

We have seen that there is something of a transformation occurring in the salamander at the beginning of its adult life, and a still greater one in the frog, when gills and tail are lost, new mouth-parts are acquired and the lungs and the great hind legs become functional. Indeed, we should not fail to recognize a sort of transformation in ourselves during our earlier years, when our first set of teeth drops out and we develop another and larger one; and in other changes that occur later, in adolescence. But the most remarkable examples of metamorphosis, as well as the most available for study, are found among insects, and these will serve us for illustration of this phenomenon.

**The transformations of insects.** — In all of the winged insect groups there is a considerable change of form at the time of entrance upon adult life. According to the extent of

this change the metamorphosis is said to be incomplete or complete. If incomplete, there are three principal developmental stages: egg, larva (or nymph) and adult; if complete, there are four such stages: egg, larva, pupa and adult. A grasshopper (fig. 136) will illustrate the first. A beetle (fig. 137), the second.

The young grasshopper is much like the adult in form and appearance. It feeds on the same herbage and jumps in the same manner by using its strong hind legs. Its wings, however, are rudimentary little buds on its back, and its reproductive organs are undeveloped. At transformation these parts appear in final functional form. The wings undergo an enormous expansion when released from the larval wing sheaths into which they have been compressed.

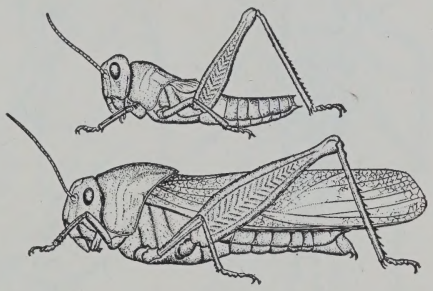


FIG. 136. Young and adult grasshopper.

The beetle larva is quite unlike the adult. It has no visible wings. Its head and body are of different shape. Its antennæ and legs are not at all the same, and it has two tails that the adult lacks altogether. In the case of the beetle, between larva and adult a pupal stage intervenes. During the larval period growth is completed. The last larval casting of skin discloses the pupa with the wings, legs, antennæ, etc., of the adult showing, but not yet functional. The pupa does not feed nor grow. It remains quiescent within its cell until the process of making over is completed. Then the casting of its skin discloses the adult beetle.

Here is something new in ontogeny. When differences in form between larva and adult have become so great that a rapid change from one to the other is incompatible with the ordinary use of the organs, the quiescent pupal stage comes in as a transition stage, a period of making over, during which the necessary extensive alterations of the body are effected.

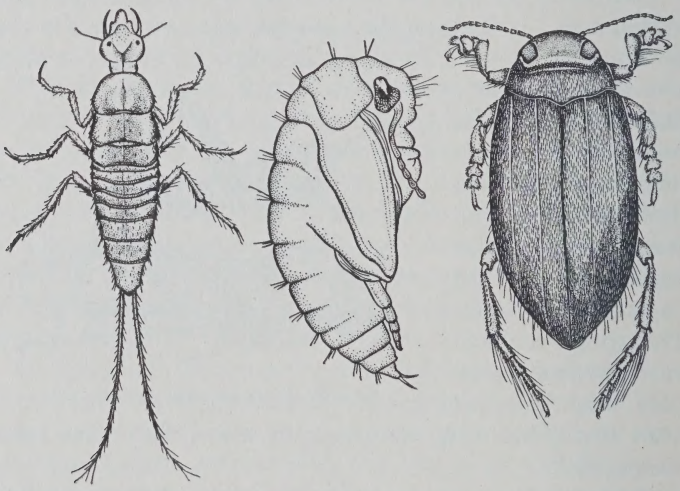


FIG. 137. Larva, pupa and adult diving beetle (Hydroporus).

The pupal stage is peculiar to insects. There are all degrees of "incompleteness" in the metamorphosis of insects. At the foot of the insect series are a few primitive wingless forms, such as the springtails, that undergo no metamorphosis, but that have only the slight changes always accompanying sexual maturity. The minimum of metamorphosis is seen in those insects whose larvæ and adults dwell together and are of like habits. Such is the grasshopper, just cited, and such are most of the bugs (order Hemiptera).

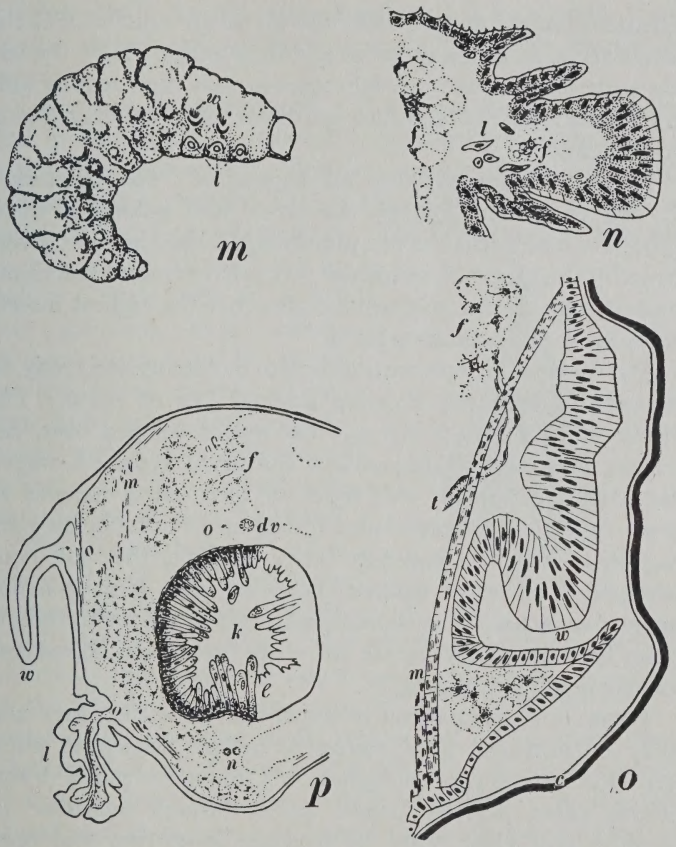



FIG. 138. Metamorphosis in the iris weevil (*Mononychus vulpeculus*). *m*, the larva at the beginning of transformation; *l*, leg buds and *w*, wing buds, showing through the skin.

*n*, longitudinal section of a leg bud of the larva, showing three principal divisions: *f*, the remains of fat cells; *l*, leucocytes.

*o*, vertical section through the wing bud of the larva; *w*, the point of the wing that is to be, with a shelf of epidermis projecting below it; *c*, the loosened cuticle; *f*, fat; *m*, muscle; *t*, air tube (trachea).

*p*, Cross section of a larva just before its final transformation to a pupa: *w*, wing and *l*, leg are now exserted, and the latter shows differentiation into femur, tibia and tarsus; *k*, stomach; *e*, digestive epithelium; *n*, double nerve cord; *dv*, dorsal blood vessel; *f*, whole fat and *o*, *o*, *o*, dissolving fat; *m*, new muscle fibers forming.

Greater changes appear when the larvæ are aquatic and the adult aërial as in the mayflies and dragonflies. Here the larvæ show independent specialization in that they acquire gills for aquatic respiration, which are discarded at transformation to the adult.

**Larvæ.** — There are also all degrees of "completeness." If one compares together the larvæ and adults of those groups of insects that have a pupal stage he will see that divergence in their form accompanies progressive change in habitat and manner of life. He will see also that the highest insects have the most degenerate larvæ.

The larvæ of insects with complete metamorphosis may be arranged in a series showing gradual loss of parts. The beetle larva shown in fig. 137 has well developed eyes, antennæ, legs, and mouthparts of the usual type. A weevil larva or a caterpillar will show all these parts reduced in size. In a timber beetle larva (grub) or a bee larva they are vestigial; and in a house-fly larva (maggot) they are gone altogether, so far as external parts appear. This is a fine regressive series. This is progress in regression, for the adults from these most degenerate larvæ are highly specialized and clearly dominant insects.

**Pupæ.** — A comparison of pupæ will show that they also may be arranged in a regressive series. Mosquito pupæ are free swimming "wrigglers." Caddis fly pupæ, living within cases, actively propel water through them for air supply; and when ready for transformation they tear open their cases and swim to the surface of the water. But the pupa of a bee or a fly is quite incapable of such activity.

In this stage, besides the development of new tissues, there is going on a destruction of old ones that are not suited to the needs of the adult, and a reconstruction of their materials in a new form. The pupal stage thus becomes one of peculiar

helplessness in the life of the insect, and it is generally spent in the shelter and seclusion of a pupal cell or burrow or cocoon.

Larval life is abbreviated. The larva stores fat rapidly, and in relatively large quantity, postponing the final elaboration of it into organs. And the amount of fat in its body is more or less proportionate to the extent of the changes to be made during transformation. The advantage of this lies in the ability of such an insect to avail itself of a rich but transient food supply. A generation may be reared on the fallen carcass or the ripe fruit before it is decomposed, or in the rich endosperm of the developing seed before it has hardened.

FIG. 139. Section of a cone gall of the pussy willow. *a*, larva of the gall maker; *b*, a scale-eating caterpillar; *c*, a saw-fly larva; *d*, eggs of a meadow grasshopper; *e*, little red larvæ of a guest gall midge.

This destruction of larval tissues during the pupal stage is one of the most remarkable deviations from the ordinary progressive course of the life cycle. Similar processes occur wherever larval organs are to be made over. The tadpole's tail does not drop off; that would be a waste of valuable organic materials. It is reabsorbed: i. e., it is dissolved and transported and used again for the building of other parts. The agents of the reabsorption in the tadpole are leucocytes that have turned temporarily to a diet of muscle fibers (and are called during their tissue-eating period, *phagocytes*). The phenomenon is called *phagocytosis* (see fig. 140).

Some of the tissues of the insect larvæ are eaten and transported by phagocytes. Others appear to be self-dis-

integrating; their nuclei divide extensively and become very small and then gather about themselves the reintegrated remains of the old cytoplasm and of dissolved fat cells, and fashion them into new cell bodies, often constituting organs of very different form in the adult. The process is somewhat like a return to an embryonic condition, followed by a new embryonic development, wherein the fat of the larva stands in the stead of the yolk in the egg. If at the height of metamorphosis one cut open a pupa that has developed from any of the more degenerate larvæ, he finds little semblance of organs, the greater part of the body being reduced to a fluid mass which flows out at every cut.

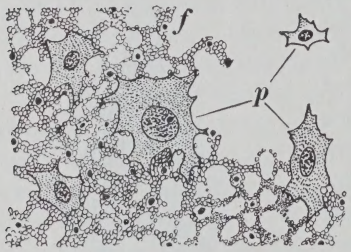



FIG. 140. Phagocytosis in the fat of the abdomen of the iris weevil. *f*, fat; *p*, phagocytes.

Not all of the body is thus destroyed, however; there are preserved little islands of regenerative cells in all the principal parts of the body from which their respective continents will be reformed. In the walls of the stomach, for example, there are grouped rings or masses of little cells, rich in protoplasm, by which the epithelium of the new stomach will be developed. The undeveloped legs and wings exist in the larva as little buds of active cells, attached to the inner face of the body walls. From these legs and wings now grow out, at first beneath the larval skin, to be freed at its last moulting. About the bases of these organs and from other regenerative cell masses in the wall itself, the new body wall is developed.

There are external and easily observable signs of these wonderful internal processes. A little white larva that lives

inside the cone gall of the pussy willow (fig. 139) is very favorable for showing them. This is the larva of a little black two-winged gall midge. It lives in the center of the gall. Grown larvæ, ready for transformation may be found any time in winter after the first heavy frosts. They are then awaiting the return of the warmth of spring, and if brought into a warm room their metamorphosis will begin at once. If collected in some numbers and brought indoors a few at a time at intervals of about a week, after about a month the whole story of metamorphosis may be well read by a careful examination of the series. [1]

The central cavity of the gall may readily be exposed by sinking the end of a knife blade or scalpel lengthwise through the end of the stem in the base of the gall, and twisting laterally, laying it open. Although the blood is red, the grown larva will appear white, because it is filled with opaque white fat. As the dissolution of the fat proceeds the red color of the blood will reappear. The progress of the pupa in metamorphosis may, therefore, from the first be gauged by the extent of the red color; later, as the end of the pupal period approaches, the black pigmentation of the adult will gradually overspread the surface, beginning with the eyes.

[1] If the air of the room be too dry they may die of evaporation. To prevent this give the galls daily a dip in water.

## CHAPTER IX

# ORGANIZATION

### I. Racial

The distinctive phenomena of living things are growth and reproduction. Every species is a "going concern"; organized; whole; complete in itself; a member of the household of nature. However great its changes of form or shifts of station, these are bound up together in an organic unity, wherein part responds unto part, and change follows change in ordered succession.

Growth precedes and conditions reproduction. Growth accumulates a surplus, and makes ready for a shift of energy from body-building to offspring-rearing. The life of any species is an endless succession of generations, starting at a common level, and running the same course.

The normal use of the vital surplus is provision for the next generation. Let us now note in concrete examples how completely the forces of the organism are marshalled to this end. In mammals, the burden of reproduction has been imposed by nature very unequally upon the sexes. It falls most heavily upon the female; and the surplus energy of the male may be put to use in the development of fighting equipment, as illustrated by the antlers of the male deer. The story of the development of these has been well told by Lloyd Morgan as follows: —

"There is perhaps, no more wonderful instance of rapid and vigorous growth than the formation of antlers of deer. These splendid weapons and adornments are shed and renewed every year. In the spring when they are growing, they are covered by a

dark skin, provided with short, fine, close-set hair, and technically termed 'the velvet.' If you lay your hand on a growing antler, you will feel that it is hot with the nutrient blood that is coursing beneath it. It is, too, exceedingly sensitive and tender. An army of tens of thousands of busy living cells is at work beneath that velvet surface, building the bony antlers, preparing for the battles of autumn. Each minute cell knows its work, and does it for the general good, so perfectly is the body knit into an organic whole. It takes up from the nutrient blood the special materials it requires; out of them it elaborates the crude bone-stuff, at first soft as wax, but ere long to be as hard as stone; and then, having done its work, having added its special morsel to the fabric of the antler, it remains embedded and immured, buried beneath the bone products of its successors or descendants. No hive of bees is busier, or more replete with active life than the antler of a stag as it grows beneath the soft, warm velvet. And thus are built up in the course of a few weeks those splendid 'beams' with their 'tynes' and 'snags,' which, in the case of the wapiti, even in the confinement of our Zoölogical Gardens, may reach a weight of thirty-two pounds, and which in the freedom of the Rocky Mountains, may reach such a size that a man may walk without stooping, beneath the archway made by setting up upon their points the shed antlers.

When the antler has reached its full size, a circular ridge makes its appearance a short distance from the base. This is the 'burr' which divides the antler into a short 'pedicel' next the skull, and the 'beam' with its branches above. The circulation in the blood vessels of the beam now begins to languish, and the velvet dies and peels off, leaving the hard, dead bony substance exposed.

Then is the time for fighting, when the stags challenge each other to single combat, while the hinds stand timidly by. But when the period of battle is over, and the wars and loves of the year are past, the bone beneath the burr begins to be eaten away and absorbed, through the activity of certain large bone-eating cells, and, the base of attachment being thus weakened, the beautiful antlers are shed; the scarred surface skins over and heals, and only the hair-covered pedicel of the antlers is left."

**The response to fertilization.** — Antler development on the part of the male is no less remarkable, although far less important, than the organic response on the part of the female that follows upon fertilization of the egg and results in the production and nurture of the young. Figure 141 is intended to show how quick is this response to fertilization in the common spreading dogbane. If a flower fail of fertilization it dies, but if fertilized, the fruit which then develops from it may reach full size before the last of the flowers on the same peduncle have faded.

FIG. 141. New seed pods of the spreading dogbane (Apocynum), showing quick response to fertilization.

**Diversions of vital energy.** — Such intermittent activities of male and female as these just cited make the greatest demands upon the resources of the body; but they are entirely normal to it. They are provided for in its organization. Outside agencies also may draw upon these reserves of energy and of substance. Parasites do this to the great detriment of the host species. Gall-makers do it, and with some peculiar and surprising consequences. Man does it when he robs the hen of a part of her eggs, or the cow of a part of her milk, or uses the surplus strength of the stallion to draw his wagon.

Indeed, it is most interesting to note how man has manipulated the energy of his domesticated beasts in the practices of animal husbandry.

1. First, he increases the surplus by providing for them a sheltered life, thus easing the struggle for existence. He gives

them food, and provides shelter, and removes enemies and competitors.

2. Then he conserves this surplus by castrating the males (all except his breeding stock). Thus, by removal of the sex organs he insures that their energy will not be wasted in fighting and breeding activities; that they will be more quiet, more easily managed if draft animals; or will put on fat more quickly if meat-producers. So he encourages bodily growth by repressing reproductive activities.

The poultryman does the same with his male fowls, and in addition, when he wants more eggs he shifts the energies of the females to increased egg production. This is possible with fowls because the production of eggs is followed by their incubation. Both are exhausting tasks.

1. First, he removes the eggs as fast as they are laid (all except a nest egg, which may be a china egg). This keeps the hen laying; for she will not begin brooding until she has a sufficiently large clutch of them to sit on comfortably (comfortably, to her mind). By this means a hen pheasant that would normally lay a dozen eggs, and then would stop and sit on them, may be induced to lay a hundred eggs.

2. Next, he substitutes a machine to do the brooding. No machine can produce hens' eggs, but an incubator may be used to hatch them.

**The phenomenon of gall-formation.** — Galls are curious overgrowths of the tissues of plants. The cone gall of the pussy willow (fig. 139) is an example. This abnormal growth upon the tips of willow twigs is to be seen by every stream side. It is caused by a small midge that deposits her egg in the terminal bud of the willow shoot in the spring. The shoot begins to grow. The egg hatches. The resulting larva feeds upon the soft tissues of the apical bud, and thus irritates or stimulates them to produce this remarkable overgrowth. It

is not like anything normal to willow development. It is a cone; and willows do not normally produce cones. The cone is composed of scales, but the scales are not like the scales of willow buds, nor are they like willow leaves; they are large and thick and hairy. They are close laid, and together they enclose a little central cavity that is exactly suited to be the home of this midge through nearly the whole of its life.

All this cone development is superadded to normal growth. At the end of the growing season one may find twin shoots, one normal, and the other with a gall at its tip, equal in length and in leafiness, differing visibly only in that one of them through the stimulus of this midge has been induced to go on producing this great excess of parts.

It is a marvelous thing that this frail insect should be able to compel the willow plant to produce for it in such fashion both food and shelter. Indeed, so great is the excess produced that other insects (as indicated in our diagram) may take advantage of it. But we are here concerned with the overgrowth itself. The gall grows with symmetry and with a definiteness of size and form equal to that of the leaves or of any other normal and usual part of the plant.

The gall begins as a breaking away from the pattern set for the new willow shoot. It ends by being brought under control. It is incorporated into the organization of the willow, and each willow species attacked by this midge produces cone galls just a little different in specific details from those that grow on other kinds of willows. It, also, is organized, and has a growth pattern of its own.

## II. Individual

The body of a warm-blooded animal is a bundle of devices for the maintenance of stable internal conditions. Exposed

alternately to heat and cold, to dryness and moisture, to dearth and to excess of all the stuffs that compose its substance and that come in its food, it must keep very close to a normal condition in order to remain alive.

Consider, for example, the heating and cooling of our own bodies. The normal temperature of the blood is 98.6 degrees Fahrenheit. In health the daily variation from this is hardly more than one degree. It is lowest about 4:00 A.M., and highest in midafternoon. A rise of more than a degree we call a fever; a fall we call a chill. This remarkable uniformity is wholly independent of the great changes in the air temperatures about us, which, as we well know, may greatly exceed 100 degrees.

The advantage of this stability of temperature is obvious. Vital activities may proceed normally, whatever the rise and fall outside. We do not have to hibernate in freezing weather as do all the animals that lack temperature control.

The body is warmed by oxidation of food within, and cooled by dissipation of heat from its surface. Oxidation goes on wherever there are living cells. It furnishes the energy for cell metabolism. Foods, especially carbohydrates, are consumed, like coal in a furnace. Their latent potential energy appears in movements and in heat, most of it as heat. The blood is warmed, and coursing everywhere, it tends to equalize the temperature of the whole body.

Somewhere in the body there exists a control that, like a thermostat, automatically regulates its temperature. It is believed to be in the midbrain. Should the temperature of the body rise too far, a message goes out from the sympathetic system through the *vasodilator nerves* to the muscles of the little arteries of the skin. They relax, dilating the vessels; more blood is brought near the surface, where evaporation, with consequent cooling, results. If this is not sufficient, the

sweat glands are activated. Finally we began panting, which increases the amount of evaporation from the lungs.

Conversely, when we begin to feel cold, the muscles of the little arteries in the skin are stimulated through another set of nerves (*vasoconstrictors*) to contract, insuring that less blood will flow near the surface. The skin becomes visibly paler. Evaporation is restricted. If this be not enough, more fuel is fed to our internal combustion engine. This fuel is the sugar that is stored as a reserve in the form of glycogen in the liver. The stoker called into this emergency service is the adrenal gland upon the kidney. Under stimulus from the cold automatically applied through the nerves of the sympathetic system, it discharges its secretion, *adrenalin*, into the blood stream. This stimulates the liver to release glycogen, which is then distributed by the blood to all the cells of the body and consumed in them with the production of heat. Shivering may then ensue, with the production of heat through muscular activity. These activities are all automatic. They have been evolved with the warm-blooded (*homoiothermic*) animal along with its structures. On these alone, birds and mammals (other than ourselves) must depend for thermal comfort. These are continually operating and all-essential controls. Man has developed some accessory devices such as clothing and housing.

As the temperature of the blood is automatically regulated so, also, by other devices far too numerous for mention here, its content of water, of proteins, of sugar, of calcium, etc., are kept within bounds of safety. First, the autonomic nervous system takes charge of slight deviations from normal in ways of which we are not conscious at all. If these do not suffice, then feelings of discomfort arise, feeling of hunger, or thirst; of heat or chill, etc., which lead to conscious efforts at readjustment.

**Hormones.** — Many organs are known to produce internal secretions, which are circulated about with the blood, and which profoundly affect the well-being of other organs. Thus, the small intestine in vertebrates, when stimulated by contact of the acidulated food entering it from the stomach, produces a substance (known as *secretin*), which, when carried by the blood to the pancreas, incites that organ to secrete and discharge its own digestive fluid.

The thyroid gland (which in us envelops the base of the trachea on the ventral side, and which is the seat of the disease known as goiter), has been found to be of great importance to health by reason of the internal secretion which it contributes to the body fluids. If, for example, the thyroid gland be removed, its loss causes both internal and external derangement. The skin thickens and becomes wrinkled, the hair falls out, the nervous balance is disturbed, and finally, death results. But if the extract from the thyroid gland of another animal of the same species be injected periodically underneath the skin, these results will not follow the removal of the gland.

The sex organs produce hormones that condition the development of secondary sexual characters. For when the spermary of a young cockerel is removed, comb and spurs and the other external signs of his sex are checked in their development; but they can be made to develop by merely grafting into his body a piece of the spermary of another cockerel.

## III. Regeneration

An organism, unlike a machine, is capable of making its own repairs. If a part be removed it may be replaced — by redevelopment. This is called *regeneration*.

The slip cut from the top of an old geranium lacks roots, and when placed in wet sand in a window box, it develops a new root system out of the undifferentiated tissues of its base, and does not proceed much further with leaf development until roots are established.

The leaf alone in the well known greenhouse plant, Bryophyllum, possesses the unusual capacity to regenerate the whole plant. A detached leaf, if kept in a moist atmosphere will after a time show buds and roots developing from one or more of the notches in its margin. There is a potential growing point in each notch. If several start to grow, then there is competition between them. If a single notch be kept in contact with water, the growth will proceed from that one alone and the others will remain undeveloped. It is as if the one gains the ascendency, draws the resources of the entire leaf into itself and inhibits the development of the others.

This is hardly different from the competition between the sprouts that spring up from the stump of a tree. The one that starts first and has the favorable position gains the ascendency. Provision for increase is more than ample. The actual increase is regulated by the organism itself in accordance with environing conditions.

The capacity for regenerating missing parts varies much in different organisms. It is very great in most plants, and in many of the lower animals; but it is so poor in ourselves, that after we reach adult life we may hardly replace a patch of skin well enough to avoid a permanent scar.

**Regeneration in animals.** — If the tentacle of a hydra be cut off, another promptly grows from the stump of the old one. If the body be cut in two, two perfect hydras develop from the parts, a new foot being formed on the one and a new head on the other. Indeed, the body may be cut into many pieces, and each piece that contains the fundamental tissues, in such

relation that food can be taken, may, under favorable conditions, develop into a perfect hydra.

A single arm broken from a starfish will regenerate the body and all the other arms. But as we ascend the scale of animal life, the power of regeneration becomes more limited as organization becomes more complex and the adjustment between the organs, more delicate.

Herein lies a curb to specialization. Blood vessels, for example, are excellent agents of circulation when intact, but when cut, they wonderfully facilitate bleeding to death.

Planarians (fig. 142) are classical subjects for regeneration experiments. They are little flat worms that are commonly found in a spring-fed brook or on a wave-washed shore, creeping with a slow gliding motion on the stones. They may be cut [1] to pieces apparently without very serious inconvenience, and regenerate missing parts with great readiness. They have no parts that can be put entirely out of commission by being severed. They have no blood vessel system, nor organs of respiration. They have a sort of brain, but it is of so little consequence that when the head containing it is cut off, another one is promptly grown. The other organs all appear equally well adapted to withstand

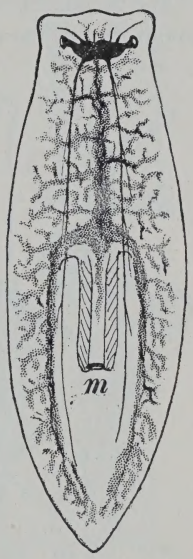



FIG. 142. Diagram of a planarian, showing food cavity in gray and central nervous system in black. *m*, mouth at the end of a cylindric pharynx that is directed downward.

[1] Such operations as are shown in fig. 143 are rather easily performed. Planarians may be cut with fine and sharp scissors while creeping, fully extended, on a piece of thin wet paper; cut paper and planarian together, at single rapid but careful strokes.

mishaps. The extraordinary food canals, branching and ramifying all through the tissues, supply with a food receptacle even the smallest piece of the body that may readily be severed.

The regeneration of the two halves of a planarian that was cut in two in the median plane of the body is shown in figure

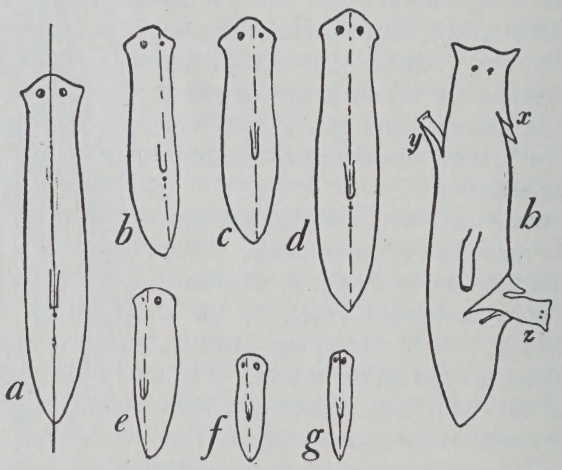



FIG. 143. Regeneration in Planaria (*a* to *g* after Morgan; *h*, after Voigt). *a*, a planaria that was divided as indicated along the median line of the body. *b*, *c*, *d*, the regeneration of the left half, that was fed. *e*, *f*, *g*, the regeneration of the other half that had no food. *h*, regeneration of pieces obliquely cleft partly free from the body: at *x* a new tail and at *y* a new head and at *z* both a new tail and a new head have appeared.

143. Such a division, every one knows, would be instantly fatal to any of the higher animals.

Most arthropods regenerate lost appendages readily, but slowly, the new appendage increasing in size a little at every moult. The crawfish is so provided against the loss of its legs that a special breaking place is developed across the

middle of the second joint in them. There is a groove across the joint, with folds of membranes inside that act as a valve to prevent excess of bleeding when the leg breaks off. Specimens are collected not infrequently, having one of the big claws much smaller than the other, and in process of regeneration.

**Normal regeneration for the maintenance of the body.** — Regeneration of lost parts is but

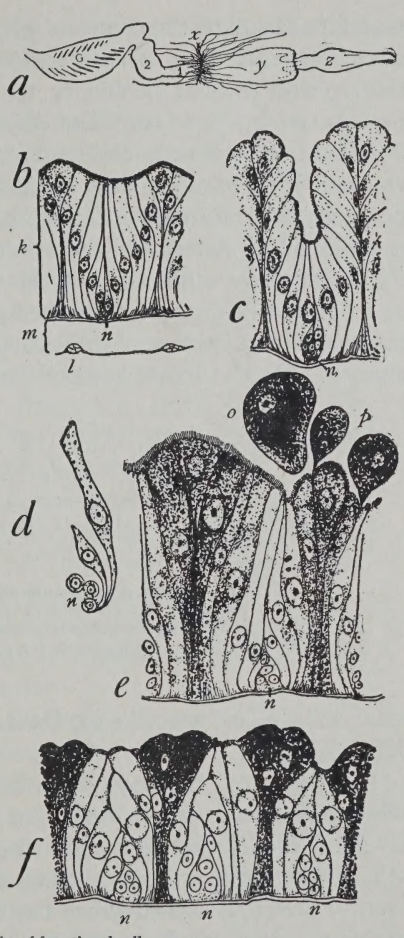



FIG. 144. Growth of digestive epithelium in a dragon fly nymph (Gomphus).

*a*, the alimentary canal as a whole; *g*, gill chamber, *1* and *2*, main divisions of the intestine. *x*, nephridia (Malpighian tubules); *y*, stomach; *z*, crop.

*b*, section of a bit of the stomach wall: *k*, digestive epithelium; *l*, longitudinal muscle fibers; *m*, longitudinal muscle layer; *n*, (as in all the following) a nest of cells for replacement of the functional epithelial cells.

*c*, the same as *b*, after fasting two weeks: note the accumulation of digestive secretion as shown in height of functional cells.

*d*, a dissociation preparation of part of one of the replacement cell nests.

*e*, the discharge of the digestive secretion after feeding. *o*, and *p*, globules of discharge: the oldest of the functional cells are thus thrown off bodily.

*f*, the replacement of the discharged cells with new ones from the cell nests *n*, *n*, *n*. Note the new (clear) cells crowding to the surface.

a manifestation of the power of growth applied in abnormal circumstances. It is a very noticeable thing when, by some mishap with tools or machinery, we knock off a finger nail and have to grow a new one; but physiologically it is not very different from getting our hair cut and having it grow out again. Our epidermis is continually being shed from the surface and new cells are continually growing up from below. An excellent example of the renewal of tissues inside the body is furnished by the digestive epithelium of the dragonfly shown in figure 144. New cells are constantly being formed in little replacement centers at the base of the epithelial layer, and the old ones, charged with the digestive secretions, are thrown off at every

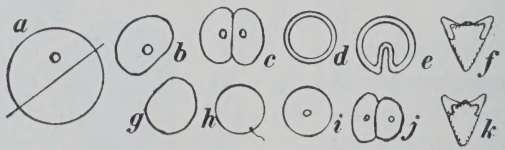



FIG. 145. Diagram of cell regeneration (after Morgan). *a*, an egg of a sea urchin that was divided as shown by the oblique line; *b* to *f* its subsequent development; *g*, the enucleate part of the egg; *h*, its fertilization by a sperm cell; *i*, *j*, *k*, its subsequent development.

meal, to be mixed with the food and by their action upon it to dissolve it.

The tissues of the body differ much in their capacity for cell replacement; some cells like those of the lowermost layer of the epidermis, retain this capacity through life, others, like nerve cells, do all their dividing in embryonic life (hence, the great size to which the brain of the higher vertebrates so early attains), and have no capacity for making good cell losses. But if they have lost the power of producing new cells, they retain the power of repairing the old ones. If a nerve fiber be severed, a new fiber may grow out from the

cell body at the stump of the old one. It is thus that a limb regains sensitiveness after being paralyzed by the cutting of a nerve.

**Regeneration in eggs and in embryos.** — If an egg cell be divided the portion containing the nucleus may reshape itself, and go on developing quite normally, as illustrated in figure 145, *b* to *f*. And if the other part of the cytoplasm be supplied with a nucleus, as by the addition of a sperm cell of the same species (fig. 207, *h*) it also may develop in the ordinary way. The two cells resulting from the first division of the egg of a sea urchin may develop as indicated in figure 146, producing two individuals of half the usual size. At first they are likely to develop as half embryos, each cell and its descendants behaving as though the other were present. Consequently the blastula when formed is open on one side; but it closes and forms a normal embryo later.

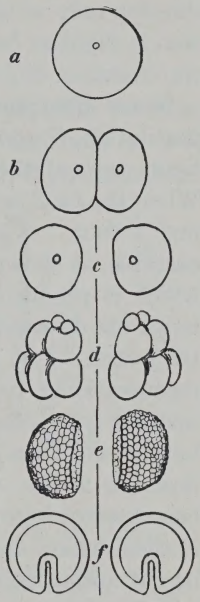



FIG. 146. The development of half embryos in divided sea urchin eggs (after Morgan). *a*, the egg; *b*, the same when it was divided: the two cells were isolated as at *c*; *d*, two half embryos in the 16-cell stage; *e*, the same as incomplete blastulas; *f*, the same later in the gastrula stage, complete but of half normal size.

In most bilateral animals the first cleavage plane lies in the median plane of the body that is to be, and doubtless, when the two cells remain together each develops its own half of the body, left or right; but the above experiment shows that either is capable of developing any part of the body. Frogs' eggs, with one cell killed at the two-cell stage, likewise develop at first half embryos, which later become whole ones. Wilson long ago showed that each of the cells of the develop-

ing lancelet, isolated at the 4-cell stage is capable of forming an embryo, but at the 8-cell stage, each cell may develop only as far as the blastula. Apparently differentiation is slight at first, and " ontogeny assumes more and more the character of a mosaic work as it goes forward."

**Some aberrancies of regeneration.** — Ordinarily after mutilation, if normal conditions be maintained, regeneration tends toward the production of parts like those removed. When the head is cut off a hydra it produces a new head, and not a foot. Very marked antero-posterior polarity, for example, is shown by the incised planarian of figure 205, *h*, which is producing new heads where the strips of severed tissue are directed forward, and tails where these are directed backward. But the expected does not always happen in regeneration. In at least one genus of earthworms, if any number from one to five of the front segments of the body be cut off, these will be replaced in like number; but if a dozen or twenty or any number of segments more than five be cut away from the front end, only five will be regenerated in their stead; and if more than the anterior half of the body be cut away, from the front end of the posterior piece there will develop not a new head but a new tail. Apparently, there is a limit to anterior polarity.

The hydroid Antennaria regenerates a new head when the decapitated stem is kept in the upright position, but a new foot when it is kept in inverted position. And stems of the hydroid Pennaria, which regenerate heads under ordinary circumstances, will regenerate roots if the cut ends are held against a solid support. From the severed eye-stalk of a crawfish (or almost any other decapod crustacean) a new eye never develops, but on the contrary, if there be any regeneration (as there is pretty sure to be if the animal be young, and the conditions favorable for growth), it is usually

a jointed appendage, more or less antenna-like, and at its best development distinctly bi-ramous, that grows out in the eye's stead.

## IV. Grafting

The parts of two organisms, if brought together by clean cut surfaces, with growing parts apposed, and held in close contact for a time, may grow together, and, if complemental parts be taken, they will thereafter function as a single organism. This is grafting. In the higher plants, on which it is most commonly practiced, the piece that is to represent the top of the combined plant is called the *cion*, the rooting piece is called the *stock*. These two parts are combined into one[1] in a number of well known ways, three of which are represented in figure 147. The essential things in the practice (with such woody plants as these shown) are (1) the bringing of the cambium or growth layer of cion and stock into close contact, and (2) protection of the cut surfaces from evaporation and from the weather.

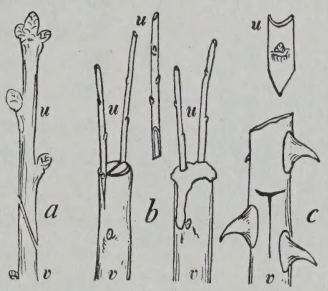



Fig. 147. Grafting methods with plants. *a*, splice grafting; *b*, cleft grafting; *c*, bud grafting (or more commonly called budding). *u, u, u, u, u*, cions. *v, v, v, v*, stocks. The second figure of the cleft graft shows how the grafting wax is applied to cover the wound.

Such combinations of the higher plants are possible only

[1] Here is an exercise in practical biology of profound significance. It is simple enough so that anyone can perform it. The practical student will want to make with his own hands this combination of parts of two species in order later to see them growing together as one. To insure success the work should be done under the direction of someone who has had practical experience.

When such a thing is done for the first time it is *an experiment;* when done at last skillfully and commercially it becomes *an art.*

between rather closely related forms (usually, between members of the same genus), and every species has its combination preferences, which can only be learned by trial. Pear cions, for example, will grow well on quince stocks, but quince cions will not thrive on the pear. Potato and tomato will thrive in either combination, and when the tomato is the cion, both potatoes and tomatoes may be produced on one plant (fig. 148).

Fig. 148. Diagram of the plant produced by grafting tomato cion on potato stock.

At its best the union is mainly a co-adjustment of transportation systems, admitting of interchange of food materials; each part retains its own individuality, and the results of the combination are not heritable. The objects of grafting are mainly two:

1. To combine the characters of two species in one individual. Thus, in order to add to the good qualities of certain apples the hardiness of the Siberian crab, apple cions are grown on crab stock. In order to adapt certain plums to southern soils, plum cions are grown on peach stock. When the vineyards of France were being destroyed by the imported American grape phylloxera (a root infesting aphid, *Phylloxera vastatrix*), the situation was saved largely by grafting wine grape cions on stocks of the hardier and immune American grapes.

2. To perpetuate in the fruiting part of the combination a valuable variety; one that does not breed at all, (as for example, a seedless grape or orange) or one that does not breed true. In such case the kind of stock used is of little consequence, except as it is a good feeder for the cion.

**Grafting in animals.** — Such combinations of parts are not so readily made in animals. The specialized contractility

of the animal body is against it. It is harder to keep the growing parts in close apposition, while being knit together. Advantage may be taken of quiescent periods in the life of the individual when stored food is available for growth, such as the early embryonic stages of frogs (fig. 149) and the pupal stages of insects, etc. Thus moth pupæ of the right age carefully cut in two across the base of the abdomen, and carefully handled to prevent loss of blood, have been united successfully in cross-combinations, the parts being sealed with paraffine while growing together. Antennæ and wings have been cross-grafted in similar manner. By uniting male bodies with female abdomens, females having the appearance of males have been produced. Similarly, male and female wings and antennæ have been combined.

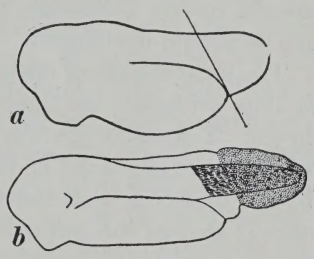



FIG. 149. Diagram of grafting operation on frog larvæ (after Harrison). *a*, the larva at suitable age for grafting; *b*, the same larva, older, to which has been grafted the tail of a larva of another species. Note that the darker pigmentation of the ongraft shows less rapid subsequent growth of the skin than the parts beneath it.

**Grafting in embryos.** — Careful tracing of cell lineages in developing embryos has shown that in normal development definite groups of cells give rise to definite parts (organs). Careful transplantation experiments involving the exchange of parts between embryos and the mutual exchange of places in the body between these parts, have shown:

1. That the first formed cells are undifferentiated and indifferent as to what parts of the body shall be built by their cell progeny.

2. The undifferentiated parts may be transplanted, and will develop the parts appropriate to their new location, irrespective of what they might have become in the old one.

3. That as growth proceeds certain cell-groups become directive centers (perhaps by reason of their strategic location) and assume localized control. These cell-groups, that are able when transplanted to compel a rearrangement of cells about themselves, Spemann called " organizers."

4. That in exchange of parts between the members of two species specific characters borne by chromosomes of the cell nuclei remain unchanged.

The separateness of the germ plasm within the body plasm is thus evidenced by transplantation experiments with embryos. The earlier grafting experiments were made to learn whether the character of the germ cells would be influenced by the alien body that nourished them. Subsequent breeding always showed the germs to carry only the characters of the parent species that furnished the sex organs.

Then it was sought to inquire whether more immature germ cells might not be changed in character through longer nurture by a foster mother. Castle made successful transplantations of the ovaries of young black guinea-pigs into the bodies of white albinos, first removing the ovaries of the white ones. These were then reared and mated with white albino males. Six young were produced and they were all black, like the ones that furnished the implanted ovaries. The genetic character of the eggs was apparently unchanged.

Since in the lower animals, as we have seen, a portion of an animal's body from which the sex organs have been removed is able to reproduce the missing parts with sex organs included, the distinction between body plasm and germ plasm is not to be too sharply drawn. Always they begin as one. They carry the genes of the egg that was their source.

The cells of an organism are not free. They are a part of a group, and are set about by restraints and limitations that seem to be imposed by the presence of the others of the group.

This is shown by the "struggle between the parts" in organisms. Favorably situated growing points develop; others are held in reserve.

As growth proceeds certain cells by reason of their position in the body are foredoomed to perish; cells that lie on the surface and must become dry and resistant to evaporation; cells that gather into themselves the substances that will form the skeleton and other hard parts; cells that waste themselves bodily in the producing of secretions (see fig. 144, *e* on p. 261). Even the cells that retain capacity for increase are definitely limited by their corporeal environment.

When a certain size of body has been attained — a stature normal to the species — then growth slows down and stops. The control lies in the organism; not in its environment. Removal of a growing shoot from a mature tree removes also this restraint; and in a favorable environment growth may again proceed up to the normal size. Cuttings from a fig tree repeated time after time, have thus kept the growth of a single individual going for centuries. The limitation lies in the multicellular organism; not in the cells.

Tissue cultures of animal cells seem to confirm this. Living cells taken from the animal body — even from the human body — and kept in a nutrient fluid (a fluid similar to the plasma of the blood) under normal conditions go right on growing and dividing indefinitely. Heart muscle tissue from a chick has thus been kept going vastly longer than the normal life time of the fowl.

**Organic harmony.** — Whether an organism develop out of an egg under normal or under artificially altered circumstances whether out of a piece of a pre-existing organism or out of pieces of two put together, if it develop at all it is pretty sure to develop with organic unity, with symmetry and proportion. Its dominant tendency is toward organic wholeness.

CHAPTER X

# THE ADJUSTMENT OF ORGANISMS TO ENVIRONMENT

"Life is response to the order of nature." — BROOKS.

In this chapter we shall attempt a more careful examination of the phenomena of *fitness*, selecting arbitrarily for the purpose, out of a world-full of examples, a few that seem fairly illustrative and typical.

Plants and animals, which were primitively much alike and lived under more or less uniform conditions, have multiplied, differentiated, specialized, and spread to every habitable part of the globe, and have become adapted to conditions of utmost diversity. Fitness to meet these conditions is a necessity of existence under them. Unfitness so pronounced as not to admit of getting a living or of leaving descendants, would mean for any species speedy elimination. That all living things are adjusted to their places in the world is most obvious; how this has come about is a subject of much speculation at the present day. We may not be able to determine whether the initiative of the variable organism or the impress of environing conditions has been the major factor in producing the results, but we can at least see the sort of facts on which all the theories advanced in their explanation are based.

## I. LOCAL ASSOCIATIONS

We go to the woods for squirrels, to the marsh for snipe and to the lake for fish. We do not expect to find either in

the place of the other; indeed, we know they could not live if they exchanged places. If we likewise go to the beach for sand or to the mine for gold, we know that either might exist as well unchanged if put in the place of the other. The gold or the sand may have lain unchanged for ages; but squirrel and snipe and fish have developed with their environment, and are developing still.

It is not everywhere in the woods that we find squirrels. They have their own particular haunts. They like the nut-bearing trees, and shun the thorny locusts. They like certain bird neighbors and dislike others.

In the water we find pickerel and top-minnows feeding at the surface, catfishes and mud-minnows feeding on the bottom, and other fishes foraging between; different forms of life at different levels; and likewise, passing out from deep water shoreward we find that every change of forage and shelter brings with it its own peculiar forms of life. The physical conditions of life in the water are still simple, but with the multiplication of individuals and differentiation of species, by reason of the stress of competition on every hand, the biological conditions have become severe. Only a few of the stronger and larger species frequent the open water, and these only when they have attained maturity; the great majority of the lake's inhabitants dwell in some restricted sphere. The great sturgeon may roam the lake at will, but the little darters, and infant sturgeons as well, must keep to shelter. The more closely we look into any environment the more we see of small and sequestered species, restricted in range and peculiar in mode of life, segregated into definite and sharply delimited haunts.

**Local distribution of green plants.** — The distribution of plants over the larger regions of the earth is determined chiefly by physical and climatic conditions. We can see the

effect of temperature by passing from the stunted and scanty vegetation of polar regions to the luxuriant forests of the tropics; of winds (fig. 150) and altitude and drouth, by crossing mountain and desert. We can see the effect of water and sunshine by crossing a narrow ravine, from its moist and shaded north slope to its dry and sunny south exposure; or we can see it by walking from the north side of our house around to the south side, and noting the different plants that cluster about the foundations.

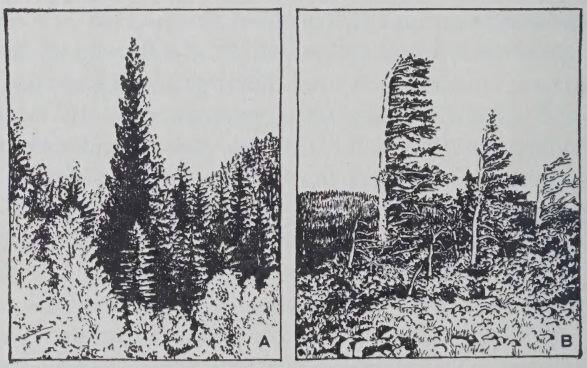



FIG. 150. Engelmann's spruce: *A*, from a sheltered valley at 7,600 ft. altitude. *B*, from an exposed mountain side at 10,800 ft.

Food and water and light are the primary requisites of plants; but green plant food is nearly everywhere present — the carbon in the air, and the other food materials in the soil; but water is not so uniformly distributed over the surface of the earth. So it has come about that the distribution of water has largely determined the grouping of terrestrial plants into *Hydrophytes*, plants accustomed to abundant available moisture, *Mesophytes*, plants that live under intermediate conditions, and *Xerophytes*, plants that live

where the water supply is scanty, and that have deep roots, and many adaptations for conserving water.

Within each of these groups the distribution of the members in relation to each other — their mutual adjustment in place — is determined more largely by exposure to light than by any other single factor. Besides food, green plants must have light, to supply the energy for growth that their simple foods lack. This is especially true of the mesophytic society, with its extraordinary diversity of size and form and habitat.

Be it forest, heath, or meadow, we always find it dominated by a few relatively large species of great vegetative vigor. Around and between these, occupying the interstices, and holding what soil and sunshine they can get, are a host of lesser species, scattered, diversified and often highly specialized as to their mode of life. A few of these plants of the undergrowth sometimes show a sort of secondary dominance, their crowns forming imperfect foliage strata at successively lower levels. Thus in the hard-wood forests of our northern mountains there is often a top stratum of crowns of maple, beech and birch at high level; a secondary stratum of the spreading tops of the hobblebush, a few feet above the ground, and a third stratum of moss, carpeting the floor of the forest.

If one would see mutual adjustment among green plants he need only select a bit of woods that has retained natural conditions, and go out into it and use his eyes. All about him will be green plants engaged in the struggle for existence, the eternal peaceful struggle for place and sustenance.

It will be most obvious that these plants are all reaching for light. The trees reach highest. A few kinds of trees lift their broad crowns to form a forest cover. They dominate the situation. They stand erect and strong. They take the "lion's share" of the energy that the sun delivers to the

woods. The others that stand in their shadow may take what is left.

Vines are the great opportunists of the woods. They are weak of stem and cannot stand alone; but by tendrils and other holdfasts or by twining, they seize upon the trees for support and they reach out into the light with leafy sprays of great length and of great quickness of growth. If they cannot reach as high as the trees, they can reach more quickly; and time is precious at the height of the growing season.

Of all woodland phenomena there is none more striking or more full of biological significance than the grand rush for light when summer comes. This is best seen where there is an opening in the woods. The great competition is near the ground level where there is standing room only for a great host of herbaceous plants and woody plant seedlings, each seeking its place in the sun, each reaching upward for light. The ones that reach highest succeed. Those overtopped and cut off from the light are suppressed.

When a great tree falls and leaves a sunny opening in the woods, then the herbs and shrubs that have been leading a starveling existence in its shadow quickly rise to the light and flourish. Among them will arise a few shifty annual and biennial weeds that manage to slip in a few seeds wherever there is an opening; but perennial plants that hold their place by continuous occupancy of it soon dominate the situation. Each season they store up food reserves, and so are able the following season to send up strong leafy shoots with which weak seedlings cannot compete. They smother the seedlings of the great trees in infancy.

Most of these perennial herbs and many shrubs as well increase by vegetative means rather than by seeds; by tubers formed underground as in the potato; by underground off-

sets as in goldenrods and asters and a host of clump-forming herbs; by stolons as in the raspberry, which reaches for an opening with long decumbent branches that strike root where the tips touch the soil, establishing there a new base. Thus each season they move one step toward a new location. Plants that depend on seeds alone for increase must start all over again from the beginning with each generation, incurring all the perils of infancy. Plants that increase by sturdy vegetative increments hold their place. They never let go.

Among the lesser plants under the trees and shrubs there is endless diversity. There are those that are early in season and those that are late. There are those that thrive best in the wet spots and others suited to the dry ones. There are large and small, strong and weak, erect and trailing, twining and creeping, shallow-rooted and deep-rooted, epiphytes and parasites; and all living together in permanent association, by their very divergencies, utilizing to the full all that nature offers for plant growth in the way of sunlight, water, and soil.

**Local distribution of animals.** — That food and shelter are the primary factors determining the distribution of animals is almost too obvious to be stated. Where to find a living and establish a home is the great question confronting every animal — even man. Terrestrial plants live where they must; but most animals are free to move about within certain, often narrow, limits, to find new pasture or to change their domicile. In a small society of green plants it is comparatively easy to find all the species, for they are fixed in place, and come out into the light, and into view; but so different is the case with animals, so small are many of them and so secretive and elusive of habit, that there is not an acre of the earth's surface of which the entire animal population is known. Even of that class of large animals to which we our-

selves belong, there are many mammals living in our own immediate environs that we seldom or never see.

Primitive terrestrial animals, recently come up from the water, were doubtless "creeping things," with feet adapted more for propulsion than for the support of the body (fig. 69, page 114). In time their descendents were able to get up on their feet and walk. With better powers of locomotion they were better able to possess the land, and they multiplied in numbers and competition ensued. Super-

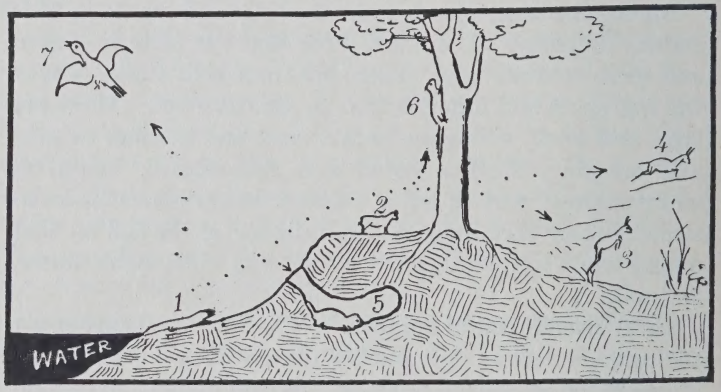



FIG. 151. Diagram illustrating lines of ecological specialization among terrestrial vertebrates.

added to the stress of competition was the direct onslaught of active enemies. Conditions became hard, and various shifts for a living were resorted to. The main lines these shifts could take were determined, however, by environing conditions. There was room to run in, if speed could be attained. There was soil to hide in, if one could dig; there were trees to climb; there was water to dive in; and if anything could fly the air offered the best of all ways of escape.

So land animals differentiated, somewhat as indicated

graphically in the accompanying diagram (fig. 151) into cursorial, fossorial, arboreal, aquatic and aërial groups.

**Size.** — Owing to the nature of the environment, its limited quantities of food, its limited and irregularly distributed accommodations for shelter, size came early to be a determining factor in the adjustment. For the small animal, while at a disadvantage in point of strength, is at a great advantage when it comes to finding food and shelter. A flag weevil can find a life's provision in one chamber of an iris seed capsule, and leave enough seed untouched to maintain the plant stock, while an ox may browse to the point of extermination all the herbage on half an acre of ground.

The kind of differentiation of habitat possible to the larger vertebrates, was possible to terrestrial invertebrates upon a smaller scale. The runners, climbers, burrowers, etc., among the beasts of the forest have their counterparts in groups of like habits among the insects of the meadow. Moreover, among the lesser animals that climbed the tree or that went down into the burrow of the beast, there was a secondary, parallel differentiation; so that on the trunk of the tree, and on the walls of the burrow we find small burrowing, running, jumping and flying forms. Indeed, even on the back of the ox there are parallel phenomena of distribution; there are fly larvæ that burrow beneath the skin, there are ticks that cling to the surface, fleas that run and jump about, and flies that take wing.

Thus, the body of the large plant or animal becomes a unit of environment for a host of dependent forms. Miniature units are found in single organic products, such as the ear of corn, the head of cabbage, or any of the larger fleshy fruits; how many inhabitants there are dwelling in each of these, and how well they are localized and adjusted in place and time, may be learned from any book on injurious insects.

**Plancton.** — In all lakes and ponds there exists a population of microscopic plants and animals suspended in the open water, or floating or drifting or swimming about, collectively known as *plancton*. It is a vast assemblage of minute, transparent organisms, the existence of which was not suspected a hundred years ago. Being invisible they were unnoticed. Yet they constitute a vast population, well adjusted to its place in the world, self-sufficient, self-maintaining, and independent of the life of the land. Both plant and animal forms show many adaptations to a life of drifting about in the open waters. Their very minuteness greatly favors drifting, but

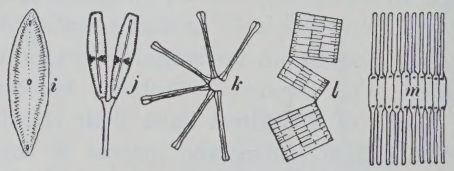



FIG. 152. Five common diatoms. *i*, Navicula; *j*, Cocconema; *k*, Asterionella; *l*, Tabellaria; *m*, Fragelaria.

in addition to this they secrete internally bubbles of gas or drops of oil, lightening their specific gravity, or they develop long hairs and spines which greatly increase superficial area, and surface friction with the water.

Plancton organisms include of necessity many chlorophyll-bearing forms, (green, or blue-green or light amber-brown in color): these constitute the producing class. Animal forms are present also in great variety, and constitute, as on land, the chief consuming class.

It is easy to gather a plancton sample from any fresh-water lake or pond. All that is necessary is to draw a fine meshed net (a plancton net, preferably one of no. 12 silk bolting cloth) through the open water. The organisms gathered in the

bottom will form a slimy gelatinous mass of faintly yellowish or greenish tint and fishy odor. A drop of this stuff mounted for the compound microscope will reveal a wonderful array of plants and animals chiefly belonging to the following groups:

Plants: diatoms (see fig. 152); desmids and other algæ (see p. 19); flagellates (see p. 48).

Animals; Protozoans (see p. 25); rotifers (see fig. 158); and crustaceans (fig. 153).

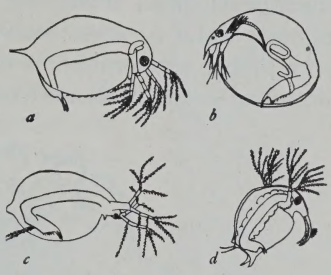



FIG. 153. Four common plancton Crustaceans (water fleas). *a*, Daphnia; *b*, Chydorus; *c*, Simocephalus; *d*, Bosmina.

Many of the plants have singular beauty of form, and the sprightliness of the living animals is delightful to observe. Their common characteristics are their transparency and their buoyancy.

## II. MUTUAL ASSOCIATIONS

**Symbiosis.** — This is an intimate association of two different organisms that enables them to live together to mutual advantage. Among plants lichens are the best examples of it. Lichens are the gray-green plants (fig. 154) that grow upon the bark of trees, on the stones of fences and on many other dry and sterile and unpromising situations. The gray encrusting species are commonest, but many forms occur. The well known " reindeer moss " is a lichen.

Lichens appear as single organisms. They were long so considered. It is convenient to describe them still as single species; for they are such, for all practical purposes. But they are composite species, each consisting of a fungus and

an alga, living together in structural and physiological union.

The form of the combination is dominated by the fungus, which develops an underlying stratum for attachment to the support, and a covering cortical layer having great capacity for resisting evaporation — of great advantage in exposed situations — and in its more porous open fibrous middle layer,

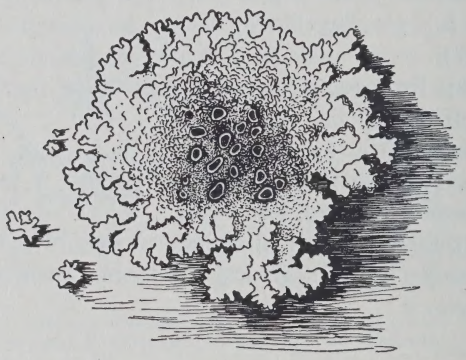


FIG. 154. A common encrusting lichen, showing fruiting cupules.

shelters a host of algal cells. The color of the latter shows through when the lichen is wet, but the true relations of parts are best made out by cutting vertical sections (fig. 155) through the thallus, and examining them with a microscope. It will then be at once apparent that the body is mainly a complex of branched fungus filaments and that the algal cells occupying the middle stratum, are in close union with some of these filaments, enwrapped by them, or indented by blunt protuberances from them.

This union is for mutual benefit. We have already learned that a plant like this fungus, lacking chlorophyl, cannot get

its carbon directly from the carbon dioxide of the air; and in such situations, there is no other adequate source of supply. Through the agency of the green alga, however, and by means of its close attachment to the algal cells, it gets carbon made up into assimilable form. It furnishes the alga in return shelter and protection and retains about it watery solutions containing the other materials for its food. The algal cells have room for growth and division; alga and fungus grow together, maintaining constant relations, resulting in a growth habit by which lichen species are known. The combination is an efficient one for meeting hard conditions of life in dry and sterile situations.

Some species that live symbiotically can be cultivated apart; but others appear to have become so fully established in this manner of life that they are able to live only in this combination.

There are other cases of symbiosis in different groups. We have already seen green hydras; the color is due to minute algal cells (*zoöchlorellæ*) living within the larger cells of the hydra, doubtless using there the carbon dioxide which the hydra cells excrete, and giving them back again the liberated oxygen for

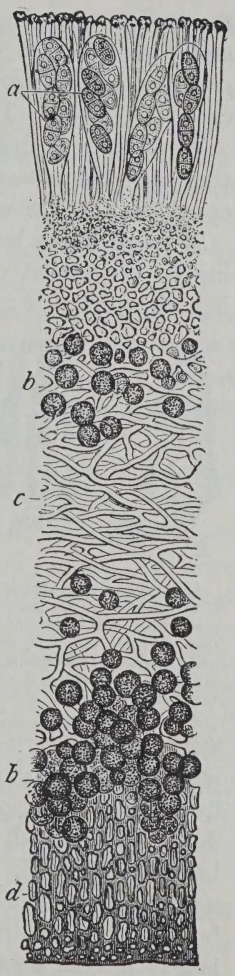



FIG. 155. Vertical section through a lobe of a common lichen (*Physcia stellaris*), showing fruiting surface above. *a*, spores of the fungus; *b*, *b*, algal cells, held among the fungous filaments, which are loosely arranged at *c*. but compacted together to form protective surface at *d*. (After Bessey.)

respiration. Attached to the roots of beech trees are molds that do for the tree the absorbing work ordinarily performed by rhizoids, while the tree supplies them with carbon products. Thus, here, also the benefit is mutual.

**Parasitism.** — Parasitism is a relation between two species that costs the one its substance and the other its independence; the one species is called *host*, the other *parasite*.

The cost to the host species may be light or severe, according to the extent of the parasitism. It is comparatively light in such case as that of the song sparrow that hatches the cowbird's egg. The latter is parasitic only to the extent of the rearing of her brood. She deposits her egg in the nest of the sparrow, supplanting a sparrow egg for the purpose, and leaves it there for the sparrow to hatch, and to feed through the nesting period.

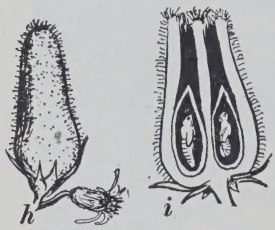



FIG. 156. Downy flower gall of the goldenrod. *h*, a gall and a flower head; *i*, a double gall split open, showing the pupa of the gall midge in one and the pupa of a (braconid) parasite in the other (right hand) chamber.

The cost to the host species may amount to personal discomfort merely, as in the case of many small external and internal parasites of the larger mammals — lice, fleas, ticks, worms, etc. — or it may amount to loss of strength or even of life of many individuals. The host may be eaten by degrees by a single large parasite, as is the midge that makes the downy flower gall of goldenrod when parasitized by the braconid shown in fig. 156; or it may be eaten by a large number of smaller parasites. In any case parasitism is the burden of the host species; but the manner of life of the host is little altered thereby.

Such is not the case, however, with the parasite, which, according to the nature and extent of its dependence upon

the host species, becomes always more or less degenerate. The cowbird, relieved of the care of her young, has lost her nesting instinct. The Indian pipe attached to the roots of trees whence it can draw manufactured carbon products, has lost its green color and its leaves. Sacculina, that famous illustration of the degeneracy that results from the parasitic habit, living in the perfect nurture and shelter afforded by its crab host, has lost all those structures and capacities by which we recognize its free living kindred.

In general it may be said that in proportion as the conditions of living become simple, easy and secure, the parasite comes to lack those organs and faculties necessary to meet hard conditions, in battling with which they were developed. This loss is the accompaniment of the sheltered life. It seems clear that, as in the individual, so in the long run in the race, it is effort that builds; disuse leads to degeneration.

The two primal functions of feeding and reproduction not even the parasite may lose; on the contrary it often develops improved feeding apparatus and increased reproductive capacity; sacculina has done so; and the liver fluke, which is parasitic on two hosts, snail and sheep, at different stages of its existence has developed an extraordinary reproductive capacity to meet the exigencies of shifting from one host to the other.

Parasitism may be either external or internal, temporary or permanent, at one stage, or during the whole life of either host or parasite, on the part of the female only (in its incipiency, the female seeking shelter for her brood) or on the part of both sexes.

Parasitism is one of many possible shifts for a living. The opportunities for it have lain in the accumulation of stores of rich organic products on the part of the larger organisms. These are available only to smaller species. Hence parasitism is a prevalent habit mainly among the smaller organisms.

The larger parasites offer like opportunities for smaller ones, and are themselves parasitized. The common bittern has as an external parasite the fly, *Olfersia*, living among its feathers. The fly has its own external parasites — the mites that cluster at the joints of the legs, where thin connecting membranes offer a point of attack.

In those groups of the Hymenoptera that are most extensively addicted to the parasitic habit, primary parasites are commonly followed by secondary parasites (*hyperparasites*), and these occasionally by tertiary parasites, the difference in size between host and parasite, being here at a minimum.

Parasites are nature's agents for regulating the natural balance. They prevent the undue increase of any species. They are themselves self regulating; for with their own undue increase, they eliminate themselves by eliminating their own food supply.

In recent years the aid of parasites has been sought to stay the ravages of noxious species, like the gypsy moth. Sometimes they are imported for this purpose; in which case care is taken to leave their hyper-parasites behind.

A moment's reflection upon the facts that have been before us in this course will make it clear that parasitism is by no means sharply distinguished from other phenomena of dependence of one individual upon another. It is living upon the living, plant upon plant, animal upon animal, one species upon another, that we call parasitism. That the boundary between symbiosis and parasitism is not hard and fast is shown by the case of the nematode that lives in the body cavity of the earthworm (cited in Chap. IV, p. 178). Ordinarily, nematodes found in such situation are parasites, but here they are found clearing up the lumps of waste chloragogue — impedimenta to the worm — accumulated in the hinder segments, and the relation seems to be one of

mutual advantage. Were the two species mutually dependent in this function, we should call it symbiosis. As it is we call it *commensalism*, and say that the nematode is a *guest*, and not a parasite. Commensalism may well have been at times a transition stage in the development of parasitic habits.

**Hibernation and æstivation.** — In our temperate climate, many warm blooded mammals, and most other resident animals, disappear on the advent of cold weather, and may be found in a dormant condition, in winter quarters. They are *hibernating*. Their temperature is barely above freezing point. Their metabolism is well nigh at a standstill. In the spring they emerge in good condition and resume their wonted activities. Nature effects great economy by limiting their foraging operations to the growing season.

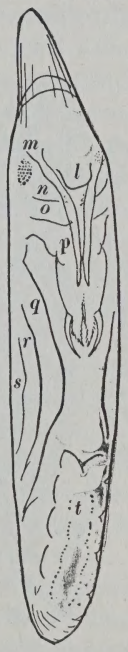



FIG. 157. The æstivating embryo of Lestes, as seen through the translucent egg shell. *l*, labrum; *m*, antenna; *n*, mandible; *o*, maxilla; *p*, labium; *q*, *r*, *s*, legs of one side; *t*, abdomen.

On the other hand, in the hot weather of summer, with its accompanying drouth, when there is not enough water to maintain activity on the part of organisms that live in temporary shoals there results another resting stage that is known as *æstivation*. Thus, through the central United States the damselfly, *Lestes uncatus*, lays its eggs in the stems of bur-reed and iris, growing in temporary pools. The eggs at first develop rapidly as in other damselflies, and reach the condition shown in figure 157 about the time that these pools normally "go dry." There they stop, and in that condition they remain until the rains of autumn refill the pools,

when they resume development, hatch out and enter the water.

There are many lesser organisms, notably the tardigrades and rotifers (fig. 158), so well adjusted to the exigencies of drouth they can get along and maintain themselves, living

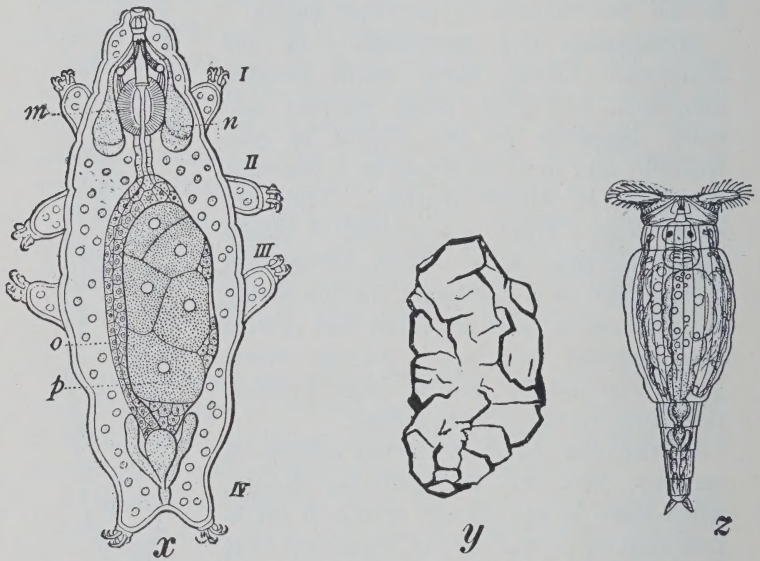



FIG. 158. Animals that withstand desiccation. *x* and *y*, a tardigrade (*Macrobiotus hufelandi*), *x*, extended, creeping; *y*, in a state of apparent death, dried; *z*, a rotifer (*Philodina megalotrocha*). Internal organs of the tardigrade shown in optic section; *m*, pharynx; *n*, salivary gland; *o*, stomach; *p*, ovary; I, II, III, IV, legs of one side. (*x* and *y*, after Hertwig, *z*, after Jennings.)

in rain water spouts, and in stone urns, that are alternately drenched with showers and baked in the sun. With every sun-baking, they are almost completely desiccated, and become contracted and wrinkled into almost unrecognizable shapes; but with the next shower they "soak up" again, and resume normal activity.

## III. Animal Coloration

We will now consider some of the details of mere superficial appearance that have to do with the associations of animals.

We pass by all that internal coloration, however brilliant, that can have no relation to the external world, because hidden from view; such as the red of blood, the yellow of fat, the iridescent tints of the swim-bladder of fishes, and opalescent tints of the inner surface of molluscan shells. We pass also that coloration of purely physiological value, even though it be adaptive, such as the black color of hibernating arctic insects, adapted to absorbing the maximum amount of heat during the short summer season; and the white color of winter animals of the same region, securing them against the too great loss of their own animal heat supply through radiation. We study that adjustment of color and form that has to do with being seen, that doubtless did not exist in the beginning, that came into existence when animals began to hunt with their eyes; that has been developed along with the perfecting of organs of vision.

There are some coloration phenomena so very common and widely distributed that they may be studied in abundant examples anywhere. These are *resemblance*, *flash colors*, *warning coloration*, and *mimicry*.

**Resemblance.** — Few animals can afford to be conspicuous — only those possessed of sufficient swiftness or agility to escape their ordinary enemies, or those possessing special means of defense. For most animals, to be conspicuous is to invite destruction. Hence the majority of animals, although conspicuous enough when exhibited in museums, are in their proper environment to be found only by careful searching.

Natural selection furnishes a simple and satisfactory explanation of resemblance. The less fitly colored, being the more conspicuous, are the ones eliminated by enemies, leaving those that are better concealed by their coloration to survive and perpetuate in their descendants their own inconspicuousness.

The most general and fundamental phenomenon of resemblance is the darker pigmentation of the side of the body that is uppermost and the shading off lighter below, to counteract the body's own shadow. This is well nigh universal. That it is of primary importance in bringing about inconspicuousness anyone may demonstrate by placing two skins of any common gray bird or mammal on the bare ground, one back upward in its normal position, and the other back downward, and then looking at them from a little distance. The conspicuousness of the gray of the body when the shadow of the body is added to it will be most striking, and the advantage of the lighter countershading will be apparent. And if one look carefully at a living or well mounted specimen of a sandpiper or a wild gray rabbit, he will see how delicately this shading and countershading is wrought; each little projecting ledge is overspread with darker pigmentation; and underneath is a lighter area, as under the orbit, under the ear, or under the chin.

That this plan of ground coloration is adaptive, is evidenced by those animals that move habitually in an inverted position, as the sloth, that travels hanging by its claws beneath the boughs of forest trees, and the back swimmer that swims with its back downward in the pond. Such forms have the countershading of lighter color on the back.

Resemblance is spoken of as *protective*, helping its possessor to escape its enemies, or *aggressive*, allowing its possessor to approach unobserved nearer its prey; but the difference is

not in the coloration, but in the purpose it serves. This finds its analogy in the devices to which men resort. The modern soldier, not wishing to offer in himself a good target, wears a khaki uniform; and the hunter, desiring to get closer to his game, adopts outer clothing of similar inconspicuous color. The gray mixed coloration of the rabbit or the roadside grasshopper or the green of the meadow grasshopper, and that of most herbivorous animals is protective; while the same colors in the lynx and the mantis, and in most carnivorous species are aggressive. However, in very many species, it may be protective toward a group of stronger species (enemies) and aggressive toward a group of weaker ones.

Resemblance is very often a matter of form and attitude, quite as much as of coloration. Burdock moths (*Metzneria lapella*) are colored much like the burdock stem on which they rest, but their inconspicuousness is greatly improved by the stub-like attitude in which they hold the body against the side of the stem.

Inconspicuousness may be brought about by loss of color. This is seen in the transparent larva of Corethra, and in many free-swimming organisms which are viewed by enemies against the lighted background of the sky.

It is impossible to judge resemblance except in its proper setting. An animal that appears conspicuous enough in the museum may be well concealed in its native haunts. Certainly the leopard frog with its green skin covered with black blotches surrounded by yellow rings is conspicuous enough sitting on a white plate in the laboratory, but anyone who has collected this frog knows it is very hard to see until it jumps. Sitting amid the mixed vegetation, its blotches fall into places among the leaves as lights and shadows, and tell no tales of its presence.

The most conspicuous of crossbands and bars may in nature be fit adjuncts of concealment. For example, the white ring about the neck of the plover, serves outdoors to detach the head from the body, and thus to break the outline of a bird into two less easily recognizable parts.

A few animals have the power to alter their coloration to match their environment. The common tree frog seated on a tree trunk may perfectly match the gray color of the bark, and a short time after being transferred to the leaves, it may be equally inconspicuous by reason of its beautiful green color.

**Flash colors.** — There is a class of conspicuous markings upon the bodies of animals that is not for continuous exhibition, and concerning the function of which the greatest diversity of opinion has been held. Since these are usually exposed intermittently in flight, we may use the non-committal name of *flash colors* for them. Such are the white bars of the wings of a night hawk, or the golden shafts of the flicker, or the white side spots of a junco's tail, or the white rump of a rabbit, exposed only when the tail is lowered in running, or the brilliant reds and blacks of the underwing moths, etc., etc. These are suddenly flashed into view when their possessor takes flight, and as suddenly tucked away again on alighting. They have been called " recognition marks " on the assumption that they enable a fleeing herd of gregarious animals of one species to keep together or help individuals to find one another more readily. But it seems in many cases at least as if they serve rather to promote the bewilderment of a pursuing enemy. For the alighting place is usually a little off to one side of the line of flight; the flight is easily followed; so easily, in fact, by reason of the flash colors, that when they suddenly disappear on the alighting of their possessor, pursuit is thrown off the track.

Anyone may convince himself of their fitness for such bewildering function by following a flock of juncos to their alighting place in the fence row.

**Warning Coloration.** — The few animals that everyone sees, moving or resting, are either able, like the great dragonflies, to escape their enemies by reason of their speed, or else are conspicuous for a purpose — possessed of some bad quality, making them undesirable for food, like the crow, or of some offensive odor, like the carrion beetle, or of some bad flavor, like the milkweed bug or of some other special defense, like the sting of the bumble bee. It is advantageous to such forms to be conspicuous. They are easily recognized and are for the most part let alone. Unlike the rabbit which runs to hide, the skunk, secure in the possession of an intolerably malodorous secretion, walks along in the open, with his great black and white tail lifted aloft, like a banner in the sky.

It is of advantage to the whole group of warningly colored animals that their colors are few and patterns simple. Their enemies, which do make experiments sometimes in youth while learning, and sometimes when greatly pressed by hunger, have fewer combinations to learn to avoid, and both parties are saved unpleasant experimenting. The combinations are (aside from black alone, which is conspicuous enough against green foliage or against the sky) black and yellow, black and white, black and green, and black and red or orange, and the patterns are broad crossbands of alternating colors, or extensive blotches.

Eye spots are the most specialized of warning colors. They are eye pictures, more or less realistically drawn by nature upon some part of the body (usually remote from the true eyes) of their possessor, and where well exposed to the view of an enemy. They are always large enough to suggest

some creature many times the size of the one exhibiting them. They thoroughly frighten ignorant people, and it is highly probable that they frighten such animals as occasionally come upon them in the open. Their efficiency must depend in part on their rather infrequent occurrence, for familiarity would abrogate alarm.

**Mimicry.** — So well established are the general types of coloration accompanying disagreeable qualities, that some animals, which lack special defense have taken them on. A black and yellow hairy-bodied robber fly so closely resembles the bumble bee with which it is associated in nature that an experienced collector may with difficulty distinguish between the two species while in flight. The fly possesses no sting or other special defense; it doubtless secures considerable immunity from molestation by reason of its likeness to the well-armed bumble bee.

Most of our commoner mimickers have taken on more or less of the coloration, form and attitudes of the stinging hymenoptera, bees and wasps; a few have mimicked ants which are distasteful by reason of the formic acid they secrete; a few have mimicked unpalatable species in other groups, the best known of which is probably the viceroy butterfly which mimics the monarch. There are some examples of coloration phenomena so fit, so admirable in every specific detail, of color, form and posture, and so well adapted to the purpose they seem to serve in nature, that they excite our instant admiration. But of the animals one may gather in an hour's collecting, many will show less fitness, and some will have a coloration that appears to be without adaptive significance.

Coloration existed before it became adaptive. There is danger of finding adaptive significance, where only structural and physiological colors are present. Such furnished

the materials out of which adaptation could proceed by natural selection. Feathers, for example, were structurally adaptable to longitudinal streaking, and birds have furnished most of those streaked patterns among animals that fit into a grassy environment. The family Syrphidæ of Diptera, which has furnished our most numerous examples of mimicry of the stinging hymenoptera, was doubtless predisposed toward the colors and forms of that family from the beginning; likewise the crane flies that imitate grass spiders. Doubtless the discerning powers of the predatory species have improved with the disguises of their prey. It would be too much to expect in the nature of the case that the devices always work, and when we examine a series of any adaptive forms, we find such varying degrees of excellence as indicate that the fitting process is still in progress.

## CHAPTER XI

# THE RESPONSIVE LIFE OF ORGANISMS

It is a long vista the science of biology opens to our imagination. At the farther end is formless protoplasm, moving with the first thrill of responsive adaptiveness to the external world. Along the way are ranged all the form-changes and all the acquired powers of organic life. At this end is the wonderful assemblage of living forms; among them, the human organism, with a mind that contemplates all, and endeavors to understand — all, and withal, itself.

FIG. 159. Melancholy.

Mind in man is made known in speech and action; the psychic life of animals, in actions alone. If the acts of animals are like those we perform under similar circumstances, we are inclined to infer that animals possess kindred psychic states. Thus, from their behavior, we think we recognize hunger and satiety, anger and fear, pain and pleasure, in the expressions of animals, and, indeed, some of the less instinctive feelings, such as curiosity in monkeys and jealousy in dogs. The great difficulty in interpreting psychic states in beings other than ourselves lies, of course, in the fact that the mind is directly accessible only to its possessor. One may not know the mind of another being except by inference. Great difficulties attend the interpretation of the psychic states of even those animals that are most like us in bodily organization, and the difficulties become insuperable in the case of animals that lack our

modes of expression. How we should express any emotion if we had to do it with a hydroid's tentacles, we cannot conceive.

Nevertheless, there is no living thing that lacks the power of making visible response to the conditions of the external world — such response as no inorganic thing ever manifests. This response may be slow, as in most plants, or rapid, as in most animals, possessed of parts having specialized contractility; but it is always in evidence, and in the last analysis is it the most distinctive characteristic of life. Even growth and reproduction are but manifestations of it.

The capacity for responding to stimuli is, as we have already seen, a property of protoplasm. When we watch the streaming of protoplasm in a plant cell we may see it accelerated or retarded with every change of temperature. A little slime-mold plasmodium placed in a half lighted position will move away from the light and into the shadow. It will creep toward a decoction of dead leaves (its proper food), and away from a solution of quinine. Such a bit of naked protoplasm, therefore, although quite destitute of organs, moves freely, and in a fundamental and important sense it both perceives and acts.

The behavior of organisms, which is the visible manifestation of their psychic life, shall be the subject of our study in this chapter.

Behavior is our only clue. By behavior we judge whether a thing is alive or not. Responses alone can show us whether there is anything within an organism capable of taking cognizance of external conditions. And responses show, also, which of the conditions of the external world an organism perceives. Psychic phenomena are essentially subjective, and our knowledge of them consists (except in one's self alone) in inferences based on their behavior.

## I. Animal Activities

### 1. *Some typical sensory phenomena of the Protozoa*

In such an organism as an amœba, which lacks permanent organs, we may observe activities of the same sorts as those above cited for the slime-mold plasmodium. An amœba creeps about freely, manifesting like movements of attraction and avoidance. It adjusts the form of its body to getting through narrow passageways; it changes its course of locomotion in avoidance of an obstruction.

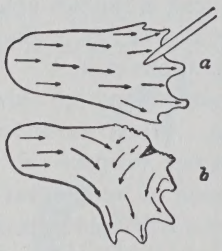



Fig. 160. Diagram of the avoiding reaction in Amœba. *a*, is the position when stimulated by a glass stylus. *b*, the reaction. Arrows indicate direction of flow of the protoplasm. (After Jennings.)

Now and then it makes a more special response to things in its environment. Coming in contact with a diatom, or other small organism suitable for food, the amœba moves toward it, extends its pseudopodia and flows about it, and finally completely engulfs it. This is a definite food-taking reaction. On the other hand, it withdraws itself promptly from a sharp mechanical stimulus, such as the prick of a glass stylus (fig. 160), a wave of movement in the protoplasm of its body away from the point stimulated, being immediately discernible.

To what sort of psychic states these simple external acts may correspond we cannot say. What the world and the things therein may be like to an animal of this sort we could only know by being amœbas awhile. Indeed, we cannot conceive what it would be like to ourselves if we had never seen or handled things, and if we had no means of knowing objects as such, but only as the obtruding parts of a general environment. Perhaps, there may be some sort of vague agreeable-

ness or disagreeableness, some sort of organic sense of comfort or of discomfort, connected with and occasioning the reactions of the two sorts.

**Organs of out-reach.** — Impermanent pseudopodia are the amœba's only means of exploring its environment, but the higher protozoans possess cilia and flagella. These are permanent organs of out-reach, in which sensory and motor functions are combined. These enable their possessor to reach out and touch an object before coming into bodily contact with it. These give time and opportunity for avoidance of collisions and for escape from approaching enemies. Indeed, if, with specialized sensibility, these be capable of receiving vibrations, they may give warning of the proximity of an enemy before coming into actual contact with it. These make the course of an animal through the water less groping in proportion to their length or sensitiveness. It is the method of a blind man exploring his pathway with his cane. The long flagellum which Euglena (fig. 18 on p. 48) swings before it as it swims, explores a relatively wide pathway.

But Euglena has also an " eye spot " at the forward end of the body, and is capable at least of discerning between light and darkness; and therefore, if compared with a blind man, the comparison should be with one whose blindness is not total. Euglena swims, as we have seen, habitually into the better lighted areas of its watery environment. In doing this it must be guided not so much by its tactile sense (which is more directly concerned with the objects of its immediate environment), as by vibrations of light coming from a greater distance.

Here, then, is the beginning of another kind of perceptive organ — one whose efficiency depends, not on the out-reach of a sensitive part of the body, but on specialized sensibility of a part to the inflow of vibratory stimuli coming from a

distance. The range of perception is by such an organ enormously increased. This fleck of pigment in Euglena is the rudiment of an organ, possessing increased sensibility to light; and it is doubtless no more an accident that it should lie in the front end of the body, than that a vertebrate's eyes should be located in its head.

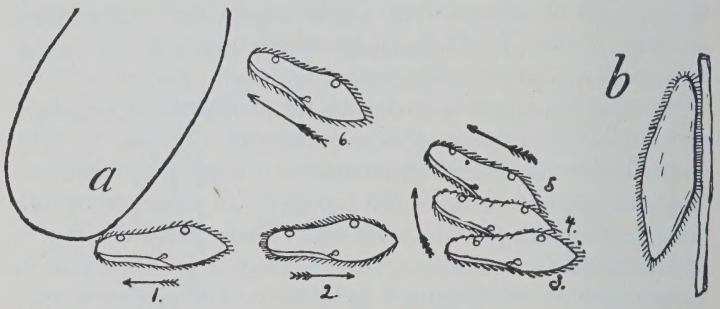



FIG. 161. Diagrams of behavior in Paramœcium. *a*, the avoiding reaction; *1* to *6*, successive positions: arrows indicate directions of movement. *b*, the contact reaction. (After Jennings.)

**Some reactions of Paramœcium.** — Improvements in the organization of the body of Paramœcium are by no means confined to the development of cilia. These are but specialized parts of the ectoplasm, which depend largely for their efficiency on further differentiation of other parts of it. The general outer surface of the ectoplasm has become thickened, giving permanence of form to the body and solidity of support for the cilia. In the underlying ectoplasm are developed strands of substance for sensory communication between various parts of the cell body; and these doubtless enable the cilia to act in unison, to stop or start or reverse their movements with promptness and efficiency. Therefore, the speed and precision of its locomotions and the promptness and extent of its responses to stimulation are vastly better than in amœba.

The specialized activities of Paramœcium have made of it a good deal of an automaton. Aside from the ordinary swimming, in a spiral course, with the oral groove toward the axis of the spiral, it has one reaction that is prominent above all others — a definite avoiding reaction. Meeting with almost any sort of stimulus it stops, ceases rotation, swims backward a little way, turns a little to the aboral side, and then starts swimming forward again (fig. 161, *a*). If the change of direction were not sufficient to clear the obstruction (or other source of stimulus), the reaction is repeated; and it continues to be repeated in a perfectly automatic manner until the course is again clear.

Food-taking in paramœcium appears to be an equally automatic and undiscriminating performance, digestible and indigestible substances being taken into the body with equal readiness.

There is also a contact reaction observable in Paramœcium. When, in swimming about, one comes into gentle contact with a bit of soft vegetable substance, it may come to rest in the manner shown in figure 159, *b*, with a number of its cilia extended in direct contact with the object. Thus, it may remain quietly, as if at a satisfactory anchorage, for a considerable time. Doubtless it is in the neighborhood of such soft substances that its proper food is likely to be found. And when a paramœcium is thus resting it is less responsive than at other times to ordinary stimuli. For example, a slight mechanical stimulus, such as a light touch on the tips of its cilia, may pass unnoticed, whereas the same stimulus if applied to one not thus situated would instantly call forth the avoiding reaction.

In all the Protozoa there are certain activities (and cessations of activity, equally significant) that indicate that the actuating stimuli are of internal origin. Apparent spon-

taneity of movement may be due to external influences that escape our observation; but the constant differences of behavior of a single organism when hungry and when well fed must be due to stimuli arising out of its bodily states. When well fed, it is less active and always less responsive to external stimuli of every sort. A far more striking example is offered by the cyclic conjugating reaction of Paramœcium caudatum, which occurs at long intervals. Two complemental individuals come together for exchange of nuclear substances. These cycles suggest the breeding periods of the higher animals, during which the maturing of the sex cells occasions internal stimuli which call forth a whole train of activities that are collectively known as "breeding habits."

So the protozoa, although their acts are few in kind and simple in performance, exhibit a set of elemental reactions of the most fundamental sort.

## II. The Responsive Mechanism in Metazoa

Protozoan and metazoan are alike organic wholes. Each has developed about itself a protecting outer wall, sequestering itself from the outer world. Each has created an internal world, within which all its vital processes are carried on through the concordant action of part upon part.

Whatever organs a protozoan may develop, it is limited in this; that they must all be developed out of the parts of a single cell. In the metazoans, on the contrary, there are many more or less independent, structural units, that can be differentiated for separate functions. One set of cells may be made to serve as receptors for stimuli (end organs); another may be specialized for doing the contracting (muscle fibers), and another (nerve cells and their processes or

fibers), may be fitted for intercommunicating between the two sorts first named. The feeble beginnings of this differentiation we have noted in the hydra (page 96), and further development has been briefly traced in the earthworm (especially in the nerve cells, figure 68), and in the salamander.

The cells of a metazoan make common cause of their relation to the outside world, and, with more materials out of which to build, greater progress in differentiation is made. Systems of organs arise; digestive, circulatory, respiratory and excretory systems for performing the nutritive processes of the body, and nervous and muscular systems, for the control and coördination of all, and for maintaining proper relations with the outside world.

**Intercommunication without nerves.** — Our studies shall be of this specialized apparatus; but we will do well to remember that receptivity and action are older than nerve and muscle. These functions are too general and too important to be wholly committed, even in the highest animals, to any particular set of cells. It is the more specialized activities that are taken over by these cells, but there remain other important functions of relation that are yet fulfilled by slower processes in which nerve and muscle take small part. Manifestly, before nerve and muscle were developed interaction had to be brought about by contact of adjacent cells, as is still necessary during early embryonic development. The movement of a stimulus passing from cell to cell was like that of particle upon particle in the body of a pricked amœba (fig. 160). It is like the slow communication by word of mouth from dooryard to dooryard, as compared with the telegraphic communication of news.

When nerves develop they take on wholly the function of rapid communication between distant parts; but certain

of the other older and slower processes of the bodily economy continue to be controlled by older and slower methods. Cell still acts upon cell directly; and it acts on all the cells of the body by contributing of its products to the fluid that bathes the whole interior. Hormones, as we have seen in Chapter IX, appear to be an important part of the self-regulating mechanism.

The pituitary gland that lies above the roof of the mouth attached beneath the brain produces secretions that affect both growth and the development of sexuality; in excess, overgrowth (gigantism) results; in lack, underdevelopment (dwarfism).

Certain of the products of the ductless glands of the body have been isolated by chemical methods, and synthesized and made available for medical use. It is certain that the activities of these glands will be taken into account in the medical practice of the future.

The control that keeps life going is effected through hormones and nerves.

Hormone action is general and dispersive and slow.

Nerve action is specific and local and instantaneous.

It appears probable that to the fluid which bathes all the tissues of the body and conditions its metabolism, every cell may contribute something, and the general condition of the body may be largely determined by the totality of this contribution.

**Sense organs.** — The exigencies of animal existence demand that the functions of relation to the outside world should be performed as speedily as possible — that stimuli should be quickly received and transmitted and translated into useful acts.

The stimuli are of various sorts. Some, like the pull of gravity or the change of temperature, act constantly or

slowly, and there may be no special sense organs for their reception. Others of mechanical, chemical and vibratory nature have caused the development of sense organs of the most specialized sorts.

1. Mechanical stimuli produce the sensation of touch. Special receptors for mechanical stimuli are scattered about over the bodies of all the higher animals. They abound in the tips of outgrowing organs that are specially exposed to contact with external objects. The earlike-lobes at the front end of a planarian, and the prostomium of an earthworm are very sensitive to touch. In our own skin tactile organs are least numerous in the middle of our backs and most abundant in the tips of fingers and tongue.

2. Chemical stimuli give rise to sensations of taste and smell. Some sort of discernment of the difference between edible and inedible substances is well-nigh universal among animals. Since food is limited in quantity and distribution, there is need that it should be easily recognized. In an aquatic organism doubtless these two classes of sensation are not very different in kind; indeed they are not always sharply distinguished in ourselves. One may bite of an onion and not be very sure whether his impression of the thing is mainly of its taste or its smell. Volatile particles may travel through the air and so may reach the olfactory organ from a distance. Hence the sense of smell is less exclusively subservient to food selection, and may be made to serve other perceptive functions, such as the locating of enemies or the recognition of friends and kindred in terrestrial animals. Dogs, and many wild vertebrates, depend upon this sense apparently for a very large part of the knowledge of the world they live in.

The sense of smell in the human species is not at its best development. Anyone may convince himself of this by the most casual observation of the actions of his own dog.

We cannot know, of course, what smells are like to a dog, any more than we may know of any other sense impression of which we have had no experience; but we cannot doubt that they are to him a means of fine discrimination.

Since chemical substances must be in solution, or in gaseous form, in order that they may affect the organs of taste and smell, the receptors of these organs in terrestrial animals are withdrawn into moistened activities within the body, where they are protected from evaporation.

Since the animal body is a sort of chemical engine, it is not strange that chemical stimuli are frequently the actuating causes that call forth various responses within the body. It is by means of chemical reactions set a-going within the retina of the eye, that the weak stimuli of light vibrations are reinforced and made effective in proportion to their importance.

3. Rays of light produce the sensation of vision. At its beginning, vision is nothing more, perhaps, than a dim awareness of a difference existing between light and darkness. The eye doubtless has had a long line of antecedents. It may have begun as a red " eye spot " like that of Euglena, and may have owed its earliest efficiency as a receptor of vibrations to the greater absorbing power for radiant energy of the lower colors of the spectrum. And it may have been responsive to heat rays rather than to light rays at first.

Ability to distinguish light from darkness might help an organism to adjust itself in position, but much more than this is necessary in order that it should really see anything. In order that a picture of an external object should be formed in the mind, it must first be pictorially impressed on multiple receptors, so situated that the rays of light coming from different parts of an object may be spatially arranged. Seeing requires eyes.

There is no one of the powers of animals in which they differ more profoundly than in their capacity for light perception. Eyes are of the most diverse structural types, and in each of the main types there exist all degrees of perfection. The camera-like eye of vertebrates, with its inverted retinal picture, differs fundamentally from the compound eye of an arthropod, with its mosaic pattern and its fine adaptation for the perception of movement. The development of the vertebrate eye is one of the most fascinating chapters in biology, but far too long a story to be recounted here.

Whatever its structure, the eye consists essentially of multiple receptors combined into a single organ, and sheltered behind a transparent protective covering, the whole occupying an exposed position at the forward end of the body and in direct communication with the more important nerve centers.

Taste, smell and hearing give us of themselves hardly any conception of form or of magnitude; nor does touch, for large objects, except in successive impressions as parts are successively explored. But the eye may instantly reveal the whole content of environment, in form, in magnitude, in proportions and in action. Such are the precious powers of this incomparable organ; and so great are the advantages it confers on its possessor that eyeless animals (save when so small as to be beyond the range of ordinary vision) are practically absent from the lighted places of the earth.

4. Vibrations of air or of solids produce the sensation of sound. They also, under certain conditions, produce a mechanical effect when they fall upon a sensitive surface. And, doubtless, tones are perceived as such only by specialized organs of hearing. Sound receptors are variously located about the body, and are wonderfully different in structure in different groups of animals. The antennal hairs of a male midge that vibrate to sound waves of a length

corresponding to the pitch of the humming of the female, are freely exposed. But sound receptors are more often sequestered in some part of the body behind a mechanism (such as the tympanum and small bones of the middle ear in ourselves) capable of taking up vibrations and passing them on to appropriate nerve endings. Since sound waves tend to fill all the space they traverse, there is not the same need as in the case of eyes, that ears should be located in a well exposed part of the body. Hence, we find the sound receptors of certain grasshoppers located in the fore legs, and in others, upon the base of the abdomen. These are so different, however, from the ears of vertebrates, that we can form hardly any conception of how they work, nor any at all of the sort of sensations to which they may give rise. The ears of vertebrates, situated on the head, are placed in the direct path of passing sound waves, and trumpet-like external ears are added for concentrating these waves upon the ear drum.

Ears possess the great advantage of giving notice of the presence of friends or enemies in the darkness as well as in the light, and when hidden as well as when in the open. Well developed, they confer great powers of discrimination upon their possessor. For social organisms ears have their value wonderfully enhanced by the development of sound-producing organs. Together, these constitute the fundamental equipment for social intercourse, and for exchange of ideas.

Eye and ear are in ourselves the receptors to which we have learned as social organisms to make appeal.

**Nerve and muscle.** Pseudopodia, cilia and other organs of out-reach in the protozoa fulfill both sensory and motor functions. Separate classes of organs for these two functions are not differentiated; and probably they were not differ-

entiated at first in the metazoa. Nerves and muscles must have originated near the surface of the body, for only there could they have been in communication with the outside world. It is there we find them first in the phylogenetic series, underlying the ectoderm in the hydra (fig. 60, page 96). It is from the underlying layers of the ectoderm, as we have seen, that the nervous tissues arise in the ontogeny of the vertebrates.

It is the primary function of nerve cells to develop out of their own cytoplasm such parts of out-reach as shall serve for intercommunication between all of the other tissues and with each other. They must be connected externally with the sense organs of the body and internally with the muscles, to the end that the sensing of the things of the external world may bring about prompt and appropriate measures for dealing with them. Muscle cells must therefore be developed in connection with nerves. They are elongate cells of special contractility, connected with whatever solid supports the body may possess. They become aggregated together and integrated into muscles of increasing strength and size as the skeleton develops, giving them points of leverage and offering strength to resist their pull.

**Ganglia.** — The possession of long organs of cell out-reach (fibers) made it possible that nerve cells should be removed from the surface where they develop, into the interior of the body, where better protected from injury. The importance of the regulatory function they fulfill made this highly desirable, and we may conceive that intercommunication between the cells themselves was facilitated by the assembling of them together in groups. The simplest of these groupings we know as ganglia.

Ganglia are local centers, which exercise a regulatory function within a more or less localized portion of the body.

Their number and arrangement differ according to the structural plan of the body to which they belong. In segmented animals, like the earthworm, the ganglia are arranged segmentally, each ganglion pair of the ventral chain (nerve cord) controlling primarily its own segment. In all arthropods, as we have seen, they are arranged upon the ventral side; in vertebrates, upon the dorsal side. They are arranged so differently in the different animal phyla as to indicate that they have been brought together on different developmental lines, in accordance with the conditions offered by each structural type.

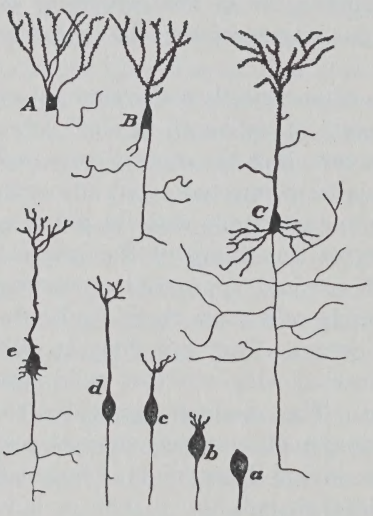



FIG. 162. Ontogeny and phylogeny in neurones of the middle layer of the cerebral cortex. *A*, *B*, *C*, corresponding cells from the adult brain in frog, lizard and rat, respectively. *a*, to *e*, successive stages of development of cells of the same sort in a mammal: the axone appears in *a*, dendrites in *b* and collaterals in *d*, (after Cajal).

**The neurone.** — Nerve cells by migration to the centers, have become widely removed from the receptors at the surface of the body. That there are nerve fibers connecting the two together has long been known (the comparison of the fibers to telegraphic lines being a very old and familiar one); but that these fibers are an integral part of the central cells is a matter of more recent knowledge, derived from the study of their development. The fiber arises as an outgrowing process from the cell body (fig. 162). There may be one (if a bipolar cell) or more (if multipolar), additional processes

arising from the opposite end of the cell and extending in different directions. The cell with all its processes is called a *neurone*. The process which becomes the fiber is called the *axone;* if it gives off branches within the nerve center for communication with other neurones, these branches are called *collaterals*. The processes arising from the other end of the cell, are typically shorter and much branched and are called *dendrites* (*dendron*, a tree).

Division of labor among the neurones has resulted in the development of two complemental sorts of them, one sort being afferent in function, and serving to conduct stimuli from the receptors to the centers, and the other being efferent, and serving to carry impulses outward from the center to incite muscle or gland to action.

**The reflex arc.** — A pair of these complemental neurones, afferent and efferent in function, in contact by their inner ends, and reaching outward the one to a receptor and the other to a muscle or gland, constitute a simple *reflex arc*. This is the unit of organization within the nervous system. It was named a reflex arc because it appeared to be a pathway over which the effect of a stimulus sent to a center is reflected back in action to view. Figure 163, *a*, shows such an arc for the body of a vertebrate. The afferent cell body (*u*) lies in the ganglion on the dorsal root of a spinal nerve; its tip (receptor) is in the skin; its opposite end enters the cord. The efferent cell body (*v*) lies in the gray matter of the spinal cord; its dendrites are in contact with termini of the axone of the other cell, and its axone proceeds outward through the anterior root of a spinal nerve to end in a muscle. This is a simple and direct nerve path, sufficing for the reception of a stimulus and the development of an appropriate automatic response.

But there are no nerve paths quite so simple and independ-

ent as indicated by this diagram. There are always bypaths which a stimulus may take to reach other efferent cells and to produce multiple response. These bypaths may be provided by various modes of branching within the nerve centers; by collaterals as indicated in figure 163, *b*, or by intercalated nerve cells that lie wholly within the nerve centers as indicated in figure 163, *c*. By reason of such connections a stimulus on a single receptor, may according to its strength, give rise to impulses in many motor nerves.

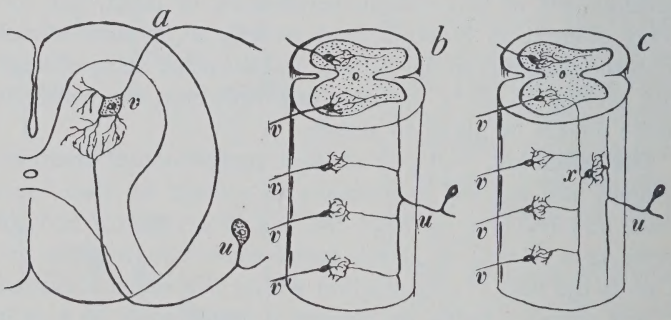



FIG. 163. Diagram of reflex arcs in the spinal cord. *a*, a simple reflex arc shown in half the spinal cord in cross section. *b*, a direct connection of one afferent with a number of efferent neurones. *c*, indirect connection through a neurone intercalated in the arc. *u*, afferent, *v*, efferent fibers. *x*, intercalated tract cell in the cord. (*a*, after Howell, *b* and *c*, after Kölliker.)

The nervous system is a unit. No reflex arc exists by itself alone. All the circuits of the body are connected, in the first instance by collaterals and dendrites, and in the next, by the arborisations of additional nerve cells intercalated within the nerve centers. Even in so lowly an animal as the earthworm, in whose segments the several ganglia appear to exercise a degree of independence and autonomy, there are abundant paths leading to adjoining segments, ultimately connecting all the segments together. If one imagine the two ganglia shown in figure 68 to be

packed (as in fact they are packed) with cells of the several types that are shown singly in that figure, he will readily conceive how numerous are the paths of possible communication by contact between the nerve cells.

But the existence of a bypath does not mean that a nerve impulse must always follow it. There are main-travelled roads, as well as bypaths in the nervous system. A stimulus at any given point has its accustomed path which it always follows; whether it shall overflow into its possible bypaths is apparently determined largely by its intensity. A finger prick, if slight enough, may merely cause the finger to be lifted in response; thus but a few muscles will be called into action. But a more vigorous stimulus at the same point may cause the arm to be jerked back, involving the action of many muscles; and a deep puncture at the same point may initiate nervous impulses vigorous enough to overflow into most of the motor circuits of the body, calling the whole muscular system into action.

This also may be likened by analogy to the distribution of stimulating news by telegraph. A slight accident excites but a little local interest among the few people who are most directly involved, but a war scare may set the wires going in every important telegraph office in the country. There is a mechanism at hand for communicating with all the motor circuits in the organism; but only so much of it is used as is warranted by the nature of the stimulus.

Doubtless these paths of nervous communication have had a gradual evolution, and have been formed to meet the needs of the organism during its long past history. For they lead in the direction of harmonious and well coördinated action. All the muscles that may be called into action by a single stimulus, work together concordantly to produce results that are in general beneficial. Differen-

tiation of parts and the development of a mechanism for intercommunication between the parts would be of no use without coördination.

Coördination is illustrated by any act that is neatly performed; all the muscles pull at the right tension, at the right time and in the right order. Want of coördination appears when the nervous system " goes to pieces," as in convulsions; or, when some unusual stimulus is applied; something of it is seen even as a result of tickling, which may produce useless and unregulated movements.

**Control circuits.** — Coördination in the nervous system tends to centralization. So long as the ganglia are of equal potency the effect produced in one by a stimulus at one point of the body may be opposed by the effect produced by another stimulus at a distant point. A homely but familiar experience shows how stimuli may interfere with each other. If a stimulus in our nose (which may be accompanied by a tickling sensation) be impelling us to sneeze, we may start a countervailing stimulus by vigorous pressure upon the upper lip, and thus we may keep from sneezing.

Stimuli are not of equal importance, nor is their importance always proportioned to their intensity. A vibratory stimulus of very slight intensity coming in the form of light to the eye may reveal the near approach of a powerful enemy. It is important that the animal heed this stimulus and make its escape, even though appealed to by the presence of food or of other congenial circumstances. It must run now; it may eat again. In other words, it is often important that all the activities of an animal be concentrated on accomplishing a single purpose — be it escape or defense; it is a matter of life or death. Hence some part of the nervous system must dominate the other parts to the extent of determining what stimuli shall be heeded, and toward what ends all the activi-

ties of the body shall be directed. If there can be a headquarters to which all stimuli of this nature shall be referred, and from which the dominating impulses shall go out to the muscles, the resulting action may be more efficient.

The mechanism for such control appears to have been found in the derived circuits within the nerve centers. We have already noted that besides the nerve cells composing the reflex arcs, there are other cells within the centers, that are situated as intermediaries between the primary circuits. These have developed secondary circuits of their own; and we have also noted that these are the media of distribution of stimuli in case of multiple responses. A single reflex arc is sensitive to but one kind of stimulus and tends of itself alone always to give but one kind of response; but these secondary circuits are so situated that they have to respond to varied stimuli coming from every quarter — sometimes augmenting each other, sometimes interfering with each other. We may not be able to say how they control action, but we may well believe that their intermediary position is advantageous in determining what shall be the totality of the organic response.

Among these secondary circuits are innumerable lines of possible communication (through points of mutual contact), and action is determined by the paths the stimuli take. If the stimuli follow paths that lead to useful and beneficial action the animal may live to have the like occur again and again, until a main-travelled road for such stimuli is established, and the action becomes habitual. If, on the other hand, the stimulus should follow unprofitable paths, leading up to the wrong action, it might, if the mistake were serious, lead to death (if, for example, a skunk seeing an approaching train, should fail to get off the track). Thus the structure of these secondary circuits is such as to furnish a means

of controlling and coördinating responses that may be quite as automatic as the action of the reflex arcs themselves. When varying or conflicting stimuli come in, which shall have the right of way is determined by the availability of the paths these secondary circuits furnish.

**Cephalization.** — It has come about in the development of all the higher animals that the most specialized of the sense organs have been located at the front end of the body; and doubtless, this fact has determined the location of the control center. The end of an animal that goes ahead first comes into contact with the new features of environment. Here then should be located the organs that are the best agencies of discovery; here, the organs that are responsive to stimuli coming from a distance; the eye, the ear, the nose and, also, the antennæ of the arthropods. Such organs as these can give knowledge of the presence of an enemy before their possessor has fallen into its grasp; they can locate food or shelter or kindred, that might be passed by blindly. It is most natural, therefore, that the part of the central nervous system with which these "distance receptors" are most directly connected should gradually assume the regulative function.

The brain is primarily an aggregate of neurones. These consist of the same parts as the other neurones — cell bodies, dendrites at the receiving end, and axones at the other end — and they are combined together in circuits, and connected more or less directly with all the other circuits of the body. They have been from the beginning most directly connected with the organs of special sense in the head; hence they are well used to receiving important stimuli from these organs of outlook, and of discharging impulses to every part of the nervous system. Certain of these stimuli have always been of paramount importance to the organism and well-worn

paths have been established for them. So, actions that are needful, are readily brought about. The nerve impulses that will bring them to pass find established channels through the well integrated mass of neurones comprising the nervous system, and they run through these channels, obliterating the effects of other unimportant stimuli. Thus, we have a mechanism which furnishes the conditions for a great variety of responses, and that may be organized by experience for the ready performance of specific acts.

Such a nervous equipment suffices for the carrying out of reactions that are determined by sense perception automatically, the right of way being given to the kind of stimuli that in the past development of the system have determined its paths. The paths are redeveloped in successive generations. The mechanism is perfected with the survival of the fittest, at least, with the elimination of the unfit, or ill adjusted. Such a mechanism gives reactions that are, therefore, wonderfully adapted to the particular set of circumstances under which they have been developed; but they are inexorably fixed in the structure of the nervous system.

Such reactions characterize the habits of most of the lower animals. The moth that flies to a candle flame is stimulated irresistibly by the light. Its ancestors for ages have flown to white objects (flowers) at night. In a proper environment there is nothing better for a moth to do than this. Thus, it gets its living. But candles being introduced into its environment, it flies to a candle, not being able to distinguish between candle light and the light reflected from a flower, or, at least, not being able to respond differently, or even to withhold response. Hence, although it may be merely singed with the first contact, it repeats the act so long as it is able to respond to the light stimulus. Thus it goes down before a peril, new to its racial experience, and

not provided for in its nervous organization. If candle lights were to become universal, its race would be doomed to extinction, unless, perchance, some line of descent should break away from traditional habits, by developing some new paths of action.

Brain action is not necessarily a whit less automatic than the action of a reflex arc. The moth has a brain, but it does not learn in this instance by experience. If past experience is reproduced at all in memory, the impulses arising from it are powerless to check those that arise from the next perception of light. Control here is based on racial — not at all on individual — experience.

**A mechanism for adaptation in the individual.** — The growth of the control centers in the nervous system has ever meant a multiplication of new channels of intercommunication between the added neurones in them. It has meant the development of accessory circuits not directly responsible for the ordinary activities of the body. It has meant more and ever more by-paths, which peripheral stimuli might or might not traverse.

The primary function of reflex response not being required of these accessory circuits, they have taken on new functions of their own, and have assumed new powers of control. Especially in the cerebral hemispheres of the vertebrate brain, where they reach their best development, they have come to preside over most of the activities of the body.

The neurones of the body are by no means to be considered merely as mechanical agents of intercommunication; they are all living cells, having their own metabolism, consuming food and developing energy, which may manifest itself in more than one way. They act upon each other as upon the other tissues of the body, in and of themselves, whether stimulated from without or not; and it is natural,

therefore, that the masses of neurones that make up the control centers should manifest themselves in new ways. Their dendrites are combined in innumerable paths, and although not reached directly by a single external stimulus, they are so connected with the peripheral circuits of the body as to be within the reach of all; and they may be influenced by all. Just how the circuits of the upper brain are influenced, we may not say, but apparently the results of these influences are more lasting here than in other parts of the nervous system. The effect of a given stimulus is no longer an unvarying impulse and action. In the labyrinth of brain paths the stimulus sets off the whole chain of impulses that have followed upon it in the past and the pleasurable or painful results of past experience are recalled in memory along with the stimulus; if pleasurable, the natural impulses that go with the stimulus may be allowed to go on to fulfillment; if painful, the neurones of the new center possess the power to direct action into new channels.

A child on seeing for the first time a pretty bee upon the window pane is impelled to catch it and examine it with his hands. If allowed to do so, he learns something about bees, by the most fundamental of educational methods — by experience. The impulse to touch the bee and the painful impressions that immediately follow become so intimately associated in the accessory circuits of his brain that the next time he sees a bee (or it may be, even a fly) on the window pane the sight of it immediately sets off, along with the impulse to touch it, other countervailing impulses arising out of the memory of the former experience. Thus the new control center steps in and prevents the expected action by initiating new ones.

Perhaps we may be permitted to compare this new control center to the referee at a game. He is not necessary to the progress of regular play, but he may with advantage step

in and control the action in case of conflict, or of the appearance of unsolved difficulties.

The development of the cerebrum as an organ of memory is the last and greatest step in the development of the sensory mechanism in vertebrates. It makes education possible. Modes of action may be altered in the lifetime of the individual, and new modes of action may be tried and if found well approved by results, may, by repetition, be made habitual. And it should be clearly apprehended that the new control center does not replace the old. The individual has his lower reflex apparatus and correlation centers in charge of the ordinary operations of his body that are necessary to keep life going, and, superadded thereto, he has the new part by means of which he may continually be improving his adaptation to environment.

**Summary.** — These, then, are the steps we have tried to trace in the perfecting of the nervous system as a seat of the sentient life:

(1) The differentiation among the cells of the primitive metazoan of (*a*) receptors (sense organs); (*b*) effectors (muscles, glands and cilia), and (*c*) adjustors (nerves connecting the other two sorts).

(2) The withdrawal of the nerve cells from the surface of the body to protected situations in the interior, and their association together to form ganglia.

(3) The differentiation of neurones, bearing axones and dendrites, and the development of polarity in them.

(4) The differentiation of neurones into two complemental sorts, and the association of these in pairs, forming reflex arcs, each pair joining sense organ to muscle or gland.

(5) The development of intercalary cells in the nerve centers, serving by their own intercommunicating processes to bind together the reflex circuits of the body.

(6) The development of specialized sense organs, in connection with some of the ganglia at the front end of the body.

(7) The development of coördination centers (groups of integrated accessory circuits) among the added neurones of the principal centers.

(8) The development of control centers in connection with ganglia at the front end of the body, establishing a brain.

(9) The development of the upper brain as the chief control center of vertebrates.

FIG. 164. The nervous system of man. (After Ranke.)

### *Relations between parts and functions in the nervous system of vertebrates*

We have already in Chapter IV, given very brief consideration to the parts in the nervous system of the salamander, their structure, and their development. Essentially the same features of both structure and development characterize all the higher vertebrates. The same parts are present and in the same relations, and they come into existence by the same developmental processes. The relatively greater development of the higher centers of the brain has also been suggested (see figure 86). Figure 164 shows roughly the location of the principal parts of the nervous system in the human body. Brain and spinal cord

occupy the dorsal axis, and cranial and spinal nerves connect these multiple centers with every part of the surface of the body. The ganglia and nerves of the organs of the cœlom are not shown.

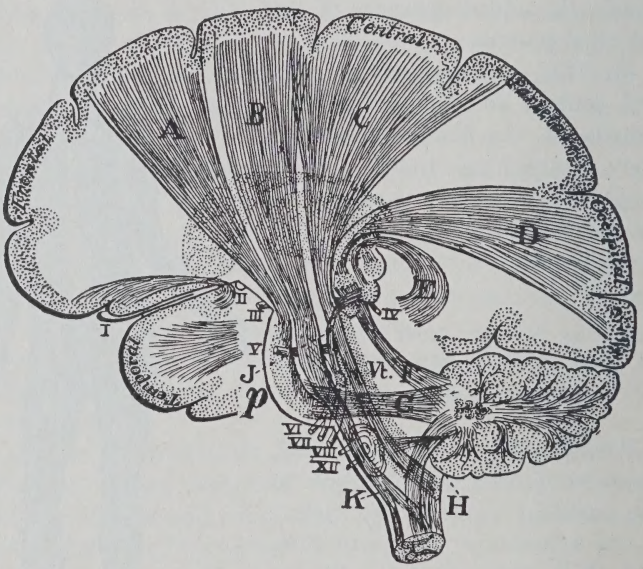



FIG. 165. Diagram of the chief tracts of projection fibers of the brain. Roman numerals designate cranial nerve roots (as in fig. 166). Capital letters designate fiber tracts, as mentioned in text. *p*, pons. (From Howell, after Starr.)

As in the salamander so in other vertebrates each spinal nerve has two roots. The ganglion-bearing posterior root is a bundle of afferent or sensory fibers that bring in the effects of stimuli from the surface of the body, and the anterior root is a bundle of efferent (mostly motor fibers), that carry impulses to muscle or gland (or, through the ventral commissures, to the ganglia of the sympathetic system). The bodies of the afferent neurones, as we have seen, compose

the dorsal root ganglion. The bodies of the efferent neurones lie in the gray matter of the central part of the cord, where they are associated with other intercalary nerve cells. The afferent fibers pass through the white part of the cord upward toward the brain by several routes. But the white matter is composed mainly in ourselves of fibers of intermediary neurones, or of efferent fibers descending from the brain. These fibers are arranged in great tracts or "columns," which are the main lines of communication between the brain and outlying ganglia. Even the main fiber tracts are too numerous for us to attempt to give an account of them here.

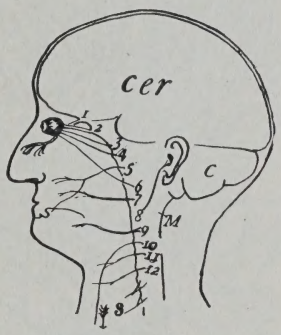



FIG. 166. Diagram of the relations of brain and cranial nerves in man. *M*, medulla, *C*, cerebellum, *cer*, cerebral hemisphere. 1, olfactory nerve. 2, optic nerve. 3, 4 and 6 oculo-motor nerves. 5 sensory nerve of the face, 7 motor nerve of the face. 8, auditory nerve. 9, the glossopharyngeal nerve. 10, the vagus nerve. *s*, spinal nerves.

Lying in the pathway of some of these bundles in the base of the brain are some very important masses of cells, that are centers of control over the most vitally important processes of the body. In the midst of the medulla, for example, lie the centers for the control of heart beat and respiration. But the greater part of the cells of the brain occupy the outer layer of gray matter of the cerebellum and cerebral hemispheres. The cerebellum is connected in an important way with the control and coördination of the involuntary movements of the body, and the cerebrum, or upper brain, is the chief control center of the voluntary activities of the body, and the organ of the mind.

The outer cellular layer of the hemisphere is known as the cortex. The chief divisions of its topography as marked out

by the convolutions of its surface are called lobes, some of which are named in figure 165. The distribution of the fibers from the cells that compose the cortex is enormously complicated, and is not fully known, but some of the major features of that distribution are indicated in the figure.

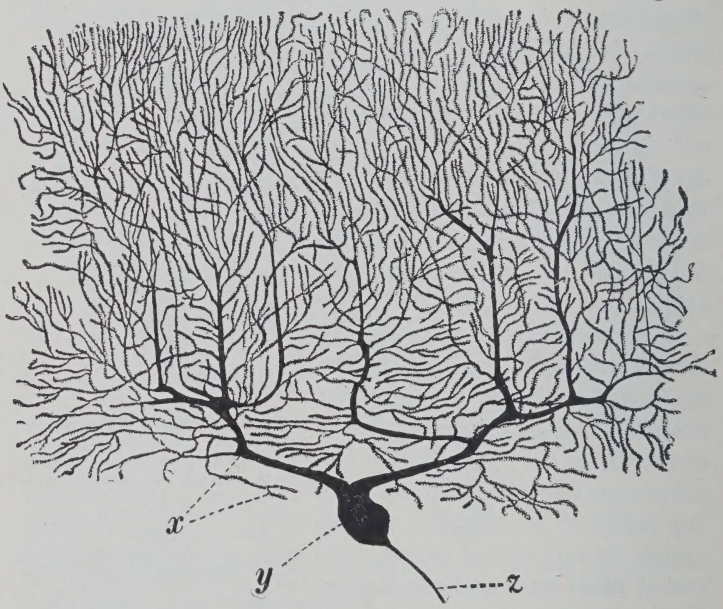



FIG. 167. A single cell from the cerebellar cortex of the human brain. *x*, its dendrites. *y*, the cell body. *z*, the axone or nerve fiber. (From Stöhr.)

This shows some of the main lines of communication between the principal centers within the nervous system.

There are three principal sorts of fibers passing out from the cells of the cortex of the hemispheres: (1) *commissural fibers* which extend across from one side to the other joining like parts of the two halves of the brain; (2) *association fibers*, which, wholly within the hemispheres and extending

between lobes, connect one part of a hemisphere with another part; and (3) *projection fibers*, which connect the cortex of the hemispheres with underlying parts of the brain and with the cord. Only the main tracts of projection fibers are indicated in the diagram. Some of these fibers will be seen to extend directly down the cord (as the fibers of the motor tract B, through which the movements of the body are controlled at will), some end in the medulla (tract C), others in the mid-brain (tract D), others in the pons (tract A), etc. The diagram also shows the three main tracts that go out from the cerebellum, to the mid-brain (tract F), to the pons (tract G), and into the cord (tract H).

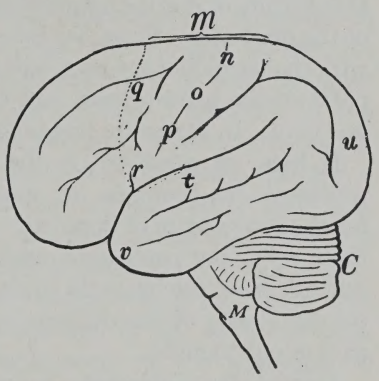



FIG. 168. Diagram of localization of functions in the cerebrum. *M*, medulla. *C*, cerebellum, *m*, the great motor area of the hemisphere with a few of the control centers approximately indicated: *n*, center for movements of the leg; *o*, for arm; *p*, for face; *q*, for head; *r*, for organs of speech; *t*, center for hearing ("brain deafness" may result from its injury); *u*, for sight; *v*, for smell.

We have seen in the salamander that the principal "distance receptors," eyes and ears and olfactories, are connected directly with the brain. Figure 166 shows the nerves of these organs, and also the other cranial nerves as they occur in ourselves.

The structure of the cortex of the hemispheres is of very great interest to us because this is the highest control-center of the body. An intelligent animal with its cerebral cortex removed becomes a mere automaton, without volition or spontaneity of action. The nutritive process may go on: consciousness is lost.

Five layers of cells are recognized in the cortex, differing considerably in form and in mode of branching of their cell processes, as well as in position, and all of them, extremely complicated. A single cell from one of the middle layers of the human cortex is shown in figure 167. The most remarkable feature of it is the extraordinary richness of the branching of the dendrites. These are interlaced and come into contact with the termini of the processes of other cells that lie in other parts of the hemispheres, and in other centers of the brain and cord. In the entire cortex there are millions of such cells.

If here, as elsewhere in the nervous system, nerve cell processes are channels for intercommunication — channels for the conveyance of impulses — how manifold are the ways these cells may react upon each other. How inconceivably numerous are the by-paths of the brain. The mere mechanical complexity of our thinking apparatus is beyond the compass of our thought.

Despite the differences in the mental powers of vertebrates, the anatomical differences of the cortex are not very great. Structurally the cortex of a rabbit is very like that of a man. The increase in number of cells is not proportionate to the increase in size in the brains of the higher mammals; the increase appears to be due rather to the more extensive development of cell processes and of intercellular substance, the cell bodies in the cortex of the brains of the higher mammals being thus spaced farther apart. The mechanism is therefore much more alike than we should expect, judging by the great differences in mental capacity. The analogy has been aptly drawn, that the structural difference between a watch that will not keep good time, and a perfect time piece may be very slight indeed.

Such is the arrangement of neurones, that every part of the cortex may receive impressions from other parts of the

nervous system and every part may give rise to outgoing impulses. In other words, every point is a center of an arc, with incoming and outgoing paths. The brain is, therefore, essentially an integration of neurones, combined in afferent and efferent intercommunicating arcs.

There are no very striking differences in structure in different parts of the cortex, and this in spite of the fact that the functional differences are more or less distinctly localized. But our knowledge of these " centers " in the cortex is very imperfect. Knowledge has been most readily arrived at in the case of the motor functions, because a stimulus applied to a given part of the cortex may produce a visible response in muscular movement. By this means (as well as by the opposite one of observing the paralysis produced by local brain injuries) the great motor area that traverses both hemispheres (*m*, of fig. 168), has been carefully explored. The definiteness of the responses to stimulation upon these centers has been aptly compared to that of the tones of a piano that result when certain keys are struck. If, however, the motor center for the leg or arm be stimulated in one hemisphere the limb of the other side of the body will move; for the motor fibers of the great tract B of figure 165 (the " crossed pyramidal " tract) in the medulla cross over to the opposite side of the body from the one in which they originate. For this reason, also, great injury to one hemisphere produces paralysis of the opposite side of the body. Conversely, the seat of injury, hemorrhage, etc., within the brain may often be located by observing what portions of the periphery of the body are paralyzed or abnormal in their action.

An experimental demonstration of the localization of some of the functions of major parts of the brain may be made in any laboratory upon a living frog. In the preceding pages we

have followed the upbuilding of the nervous system. This demonstration will necessarily follow the reverse order, taking it down, part by part, and noting the result.

First, the skin and thin flat bones of the top of the head should be removed by a few swift, deft strokes of a sharp dissecting scissors. This will uncover the brain, and the cerebral hemisphere may then be removed by a single cross cut close up under their base. Without hemispheres the frog can still perform very neatly most of its accustomed activities. If thrown into the water it will swim with perfectly coördinated strokes of its long hind legs. If stimulated it will jump. If a block on which it is sitting is tilted it will climb up and balance itself. If a living fly be put in its mouth it will swallow. But *it will do nothing in absence of stimulation;* its volitional control center has been removed.

If now the cerebellum be removed by a careful cross cut made underneath its base, and the foregoing tests be repeated, it will be seen that the movements made in response to stimulation are no longer well performed. The parts do not act in unison. The center of coördination for voluntary muscular movements has been lost.

Then if the brain be cut off at the base, the tone of all the parts will be lost, and the body will hang limp. If the cut end of the cord be stimulated all the muscles of the body may be thrown into spasmodic contractions. If the brainless frog be hung up by its head (for convenience in manipulation) reflex responses may be had by stimulating any point on its skin.

If a stimulus be applied to the flank of one side, the hind foot on that side will be lifted to rub the spot stimulated. And if that foot be held down so that it cannot reach the spot, then the other hind foot will be swung around to do it; showing a cross path for stimuli through the spinal cord.

That the nerve is the path of stimulation, may be demonstrated by uncovering and severing the great sciatic nerve. It will appear as a white thread lying between the muscles on the inner side of the thigh. Stimuli may be applied to its cut end, and the muscles of the leg will respond by contraction. This nerve forks at the knee, and if its divisions be stimulated separately specific responses related to locomotion may be observed.

## III. Types of Response

The powers of animals find expression in the responses they make to the external world.[1] The great differences we have seen in complexity of nervous organization are more or less closely accompanied by differences in mental powers, manifest in behavior. Every step in integration of the nerve paths of the body is doubtless accompanied by improvement in action. Without attempting, however, to draw a close parallel between organization and behavior, we will now examine some types of animal activity, that at least show steps of progress.

**Automatic unvarying activities.** — Two examples of unvarying response have already been before us for consideration. The avoiding reaction of the protozoan Paramœcium as we have seen, constitutes almost the entire stock-in-trade of reactions for that animal. The distance of movement backward upon stimulation and the extent of the swing to the aboral side will depend somewhat on the strength of the stimulus; but the one sort of reaction follows upon almost every sort of vigorous stimulus that the environment of the animal normally offers. And with repetition of the stimulus,

[1] The essence of an animal is in what it does. — *Aristotle.*

the reaction is repeated indefinitely, and in essentially the same manner.

The reaction of the moth to the candle flame is essentially of the same unvarying type, although it is performed by the aid of a complicated nervous system. The moth, however, has other less inflexible responses that it makes to other less dominating stimuli.

**Responses automatically varying.** — The repetition of a stimulus usually brings about a change in the behavior of an organism, sometimes an augmentation of the reaction, sometimes the entire cessation of it. A hydra will react to touch by contracting its body, and if allowed time between stimulations for complete extension of its length, it will contract again when touched, every time; but if the touch is repeated before a full extension of the body, the animal will soon cease to notice it altogether. In such an organism the stimuli must follow each other in quick succession if they are to modify action.

Garden spiders habitually drop from their webs to the ground when disturbed. This is their avoidance reaction, and it doubtless carries them often out of an exposed situation into one of less danger, and at times enables them to escape capture by enemies. A certain spider will respond, when a large tuning fork is struck near at hand, by dropping from its web. But it will cease to do this (and to put itself to the trouble of climbing up again) after the experiment has been repeated half a dozen times.

Moreover, the spider, unlike the hydra and many others of the lower animals, may, after daily repetition of this experience, become used to the stimulus of the tuning fork and cease to react to it at all after a considerable time. This would seem to indicate growth in power of discrimination between stimuli; for only an animal with some such power

could afford to suspend the reaction by means of which it escapes its ordinary enemies.

Cessation of response to continued but harmless stimulation is a widespread phenomenon in the reactions of animals. It is too familiar for much notice in ourselves. We are not long conscious of contact with our clothing after it is put on, notwithstanding that by contact we get it adjusted properly. The better the organization of the psychic mechanism, the more lasting appears to be the result of getting used to a stimulus.

**Sequences of automatic activities.** — We come now to the consideration of a class of phenomena commonly known as *instincts*. These are automatic activities, amplified and serially arranged and extended until they cover often a large part of the life of the individual. They are not essentially different from the simpler automatic acts we have just been considering. A caterpillar instinctively moves upward on its food plant; but creeping is itself a sequence of events. The participation of many sets of muscles is necessary, and these must act successively and in progressive order. Each movement is prepared for by the one that went before it. The stimulus acts through the control centers. Not the stimulus, but the state (position) of the body determines which foot shall first be lifted and swung forward.

Instincts proper are sequences of such actions, the events of the series being unlike in kind and unrepeated. The preparation of the caterpillar for its transformations is a performance of this type. When fully grown it ceases feeding, crawls to a place of security (usually away from the plant that has nourished it), spins a silken cocoon about its body and changes into a pupa. But before these things can occur it must be full-fed, it must have a store of material for further development, the rudiments of the adult organs must

have reached a proper stage of development, and the silk glands, now nearing the climax and the end of their usefulness, must be charged with the secretion that is to form the cocoon, and a host of other physical (somatic) conditions must be fulfilled. When fulfilled, we may say, speaking in figures, the ship of instinct is laden and tugging at its cables; its course is laid out from beginning to end, the points of call, the discharges of cargo, the bells that shall be rung and the whistles that shall blow are all prearranged, and only the signal to start is needed, to initiate all the events of the voyage.

The bird builds her nest when the condition of body and brain impels to it. No stimulus has any effect whatever until body and brain are ready. Maturity must be reached, and eggs must grow, and mating must take place; and when all is ready, the simplest sort of stimulus, the sight of suitable materials (straw or fiber or hair, not conspicuously different from a thousand other things the eye might fall upon), serves to set the complex activities of nest building going. The stimmulus is but the spark that sets off the powder in the mine. In itself it may be insignificant, but in its relations to the organism it is all important; for it determines the very conditions of existence. Nest building must wait on the finding of suitable materials — materials not too different from those the sight of which has elicited the nest building responses in the past, and all the subsequent acts of rearing young wait on nest building. This means that the want at any point of a stimulus that can set off an appropriate action, blocks the remaining acts of the series and leads to failure.

The perfection of instinct at its best is marvellous. Sequences of acts, that, like nest building and web spinning, are worthy to be ranked as fine arts, are performed perfectly without instruction, example or experience; performed,

perhaps, but once in a lifetime. The method of a caterpillar in spinning is as much a product of its organization as is the silk in its spinning glands. Glands and nerve cells are alike charged during development. They are alike the end results of a long evolution, with endless adaptations to conditions of life.

An ingrained habit may persist, also, like a vestigial organ after it has ceased to be of any use. Perhaps the most familiar illustration of this is the turning round and round of a dog before it lies down. The primitive dog presumably made its lair in the grass, where this was an eminently useful performance.

Instincts illustrate extreme specialization in the neural mechanism. It is fitted finely to one set of conditions, and is apt to be found wanting when conditions are altered. The moth that flies to the candle flame has left the beaten track of its ancestry, through want of discrimination between stimuli. Fatal want of discrimination is sometimes displayed toward objects of the normal environment. Thus the flesh fly is stimulated by the odor of the carrion flower and lays eggs upon the plant, where her young on hatching will find no food. The fly does not possess even such perceptive faculties as would enable it to distinguish between a flower and a dead carcass. The fly knows neither carcass nor flower, but only a certain kind of olfactory stimulus that may come from either.

**Learning by experience.** — Many of the lower animals are born educated almost to the full extent of their capacity, the possible lines of action of their whole lives being provided for and predetermined in their organization. The acts most fundamental to the preservation of races, feeding, reproduction, etc., are thus provided for in the main in all animals.

A kitten is instantly thrown into a paroxysm of defensive

movements and attitudes at the first sight or smell of a dog. A chicken flees at the first cry of a hawk, although it may be quite unresponsive to the (to us apparently) similar cry of a catbird. Nature has developed this nice discrimination by the elimination of the unresponsive. Racial experience has thus been incorporated into the organism in such manner that vitally important stimuli dominate all the activities of the body and enable it automatically to meet the chief exigencies of life.

There is, however, especially in the higher animals, a field of activity in which reactions are less stereotyped; more variable; and here lies the opportunity for learning by individual experience. This is so large a part of our own life that we have difficulty realizing how limited it is in many of the lower animals.

The sight of food that is not within reach may stimulate to activities that are predetermined only for the act of feeding, and the processes of nutrition; not at all for the method of getting at the food. A horse confined in a bare lot, is stimulated to a great variety of activities by the sight of the green grass on the other side of the fence. He does many things that yield no satisfactory results; he pushes, he whinnies, he stamps, he tugs at the toprail with his teeth, he rears, etc. But by chance he lifts the latch of the gate with his teeth, and this act is accompanied by pleasurable results; he sees the gate open. Another time he is likely to concentrate his efforts at the gate, and to lift the latch sooner, with fewer ineffective efforts. Every repetition of an act makes its subsequent performance easier, especially when accompanied by pleasurable experiences following successful performances of it. Soon he is able to eliminate all the unprofitable acts, and to lift the latch at once; he has learned by trial and error.

So we learn in infancy to walk, to talk, to play; and in later life, to acquire any wholly new accomplishment without instruction or example.

Such learning is conditioned upon the possession of a nervous mechanism that is capable of retaining the impressions accompanying a former act until the stimulus is repeated. Such a mechanism is, as we have seen, the upper brain in the vertebrates. It is an agency for reviving alongside every important stimulus the impressions that have accompanied former responses to the same kind of stimulus, action then being determined in accordance with whether these have been pleasurable or painful, whether they have been successful or unsuccessful in attaining a desired end.

It is a long step forward toward intelligence when brain circuits are able to retain impressions arising from one stimulus long enough to influence the action that shall result from the next stimulus of the same kind; for then the responses may begin to take on individual variations. It is a still longer step when the central circuits through previous stimulation and mutual interaction become able to originate like acts in absence of the original stimuli; for here initiative comes in. Then, the trial of a performance need not wait upon an outside stimulus; an autogenetic one may be substituted. Practice may go forward. Experiments may be tried. The individual may of himself learn new modes of action.

CHAPTER XII

# HUMAN BIOLOGY

## I. Nature and Nurture

The human species inherits as do other organisms. Characters of various sorts "run in families;" form characters, such as shape of nose, of chin, of fingers; physiological characters, such as left-handedness, baldness, etc.; psychological characters, such as phlegmatic or effervescent temperament, etc. But these are examples of complexes of characters, that must be analyzed to their component units before their manner of inheritance can be studied. To speak of infectious diseases as being hereditary is wholly inaccurate, for disease germs are not part of the body, but foreign organisms; they can be passed on from one generation to another only by infection; not by inheritance. There may, however, exist innate physiological weakness that favors the infection in successive generations, and infection may occur before birth as well as after.

However much the young may receive of fostering parental aid in yolk, in shelter within or without the body, in nourishment by means of embryonic membranes, etc., it has already received when egg and sperm have united, its full hereditary endowment; all else is nurture.

**Inheritance of acquired characters.** In the lifetime of the individual, the body may acquire various characters. The skin may get a coat of tan in a few days' exposure to the sun. The hands become calloused with toil. The muscles strengthen with use. Dexterity results from practice, and

by long effort we may acquire an education. But are any of these things which the individual may acquire during his lifetime heritable, or does the offspring start at the common level of its kind, nothing advantaged by whatever his individual parents may have gained? This is an exceedingly important question, the answer to which must have something to do with determining our educational policy.

In the long run all characters are acquired characters, if evolution be conceded. The question is, Can the peculiar conditions which cause new characters to develop in the body so affect its germ cells that these will develop the same characters in the next generation, even in absence of the conditions that first called them forth? When we remember the early isolation of the germ cells, their lack of participation in the work of the body, and their remoteness from contact with environment, this seems unlikely. How, for example, could the abuse of the eyes, causing partial blindness in the adult, so affect the germ cells that have no eyes, as to cause them to develop in the next generation, with proper use, the same weakness? That new characters are acquired by the individual body needs no proof; that they are at the same time acquired by its germ cells is not proved, although it has been widely believed. Mutilations of the body we know are not inherited. The loss of an eye in one generation does not prevent its perfect development in the next.[1] The tails of sheep have been docked for centuries, and yet lambs continue to develop tails in apparently undiminished luxuriance.

On the other hand, there are facts showing that the germ cells (or, at least, the sex organs, collectively) do affect the characters of the body of which they are an isolated

[1] "Wooden legs do not run in families, but wooden heads do." — CONKLIN.

part. The effects of castration (removal of the spermaries) of young animals are often very marked. The differences between a bull and a steer, for example, are very apparent in the horns and neck muscles, in voice and attitudes, in disposition, in ability to put on fat quickly, and in other characters that are equally remote from the missing sex organs of the latter. Doubtless the condition of the body does affect the germ cells also (whether well- or ill-nourished; healthy or not), but in what manner and to what extent is not readily determinable at the present day.

**The physical basis of racial solidarity.** — This we know: that with all the changes of its outward conditions, human nature changes little. Civilization advances, but civilization concerns itself with methods of nurture alone; and its gains, every individual must re-appropriate for himself. Nurture creates many artificial distinctions among men, but their nature is little altered. Good health and good spirits and normal desires for life, liberty and the pursuit of happiness are not the possession of any class or condition of men. Good brains are probably as equitably distributed as are good muscles, although the opportunity for their development may not be. Dynasties may rise and fall, systems come and go, but the racial currents run on serenely. Art and science are not transmitted in the germ; the only part of our education that is inherited is the organic part of it that is common to the race. Fortunately or unfortunately, the springs of racial progress lie very deep; and if they are not readily reached by humanitarian effort, they are at least remote from unskillful meddling. It is the common stock of germ plasm of our race that breeds our common interests and common needs, and makes it possible for us to have common schools and common law. This is the great guarantee of democracy.

**Racial differentiation.** — Nevertheless, our common stock of germ plasm is not quite homogeneous. It has had a long history. It has developed divergent tendencies. It has lived under different environments. The spirit of one people is not that of another. That the slow methods of nature have wrought changes in the constitution of her segregated strains appears in this: their civilizations differ, and though civilization be nurture, the capacity for it, the impulse toward it and the genius to modify it must be inherent. And, if this is true of tribes, it is true within each tribe, on a lesser scale. "Blood does tell." To some extent at least genius does run in families,[1] as also do criminal tendencies, the capacity for the development of either being organic. Hitherto human society has taken little account of these springs of future character.

**The meaning of nurture.** — Most organisms give little nurture to their young. They merely breed. Their innumerable progeny are scattered broadcast in a pitiless environment, and here and there, by chance, one survives. Destruction is the rule; survival the rare exception. We have already seen in our study of the plant and animal series how the dominant organisms have made their advantages secure by better care for their offspring during development; by adding food to the egg or supplying it to the embryo, and then in animals by adding housing and parental care. Ever, there is a lessening of the number of young produced coupled with increase in the care for them. The powers of the body are devoted less and less to starting new individuals

[1] I have often heard false pride of ancestry condemned, but I have not seen the true pride of ancestry explained and commended. Surely the man who is conscious that he comes of stock sound in body, able in mind, tested in achievement, and who knows that, mating with like stock and maintaining himself in health, he may hand down that heritage to his children, surely such a man may have a legitimate pride in ancestry." — K. PEARSON.

in life and more and more to the better equipment for life of those that are produced. The lioness of Æsop's fable might well boast that though her offspring were but one at a birth, that one was altogether a thoroughbred lion; and then might well care for it as though there were no lions to spare.

The eggs of some of marine animals, such as the sea urchin, may be fertilized by mixing sperms with them in a glass of sea water: and then they may be watched at one sitting through the early stages of development until they are ready to enter actively into the struggle for livelihood. There is no nurture beyond the little food that is stored in the egg, and the egg is of microscopic smallness.

The large eggs of the musk turtle, distended with yolk, as big as marbles, and several hundred in number, are buried among the rushes of the marsh, just above the water level. A few weeks of lying in the sun-warmed marsh suffice for their hatching, but they receive no parental care. The young must shift for themselves from the start.

A hen's eggs are larger and fewer — only about a dozen. Three weeks of persistent incubation are necessary to hatch them, and a still longer period of maternal care after hatching is needed to get the chicks well started on their careers. A robin's babies are fewer, hatch in a more helpless condition, require to have their food brought to them and put in their mouths, and receive the care of both parents for a long time. Months of prenatal nurture are required for the development of the young of all the larger mammals, and after birth, other months of nursing, of sheltering, of care and assistance. And to all this man adds education, which is only an extension of the original mother function. In the eye of the law it takes twenty-one years to make a man. Thus, human society has learned the first lesson of racial progress.

**The disturbance of the natural balance by conditions of civilized life.** — The rate of reproduction established by nature for the human species is far too high for civilized conditions. It was adequate to replace the losses by war, pestilence and famine in primitive society. But now that these agencies of death are in a measure controlled, the natural balance is disturbed. Without these checks the human population of the earth is rapidly increasing.

Many wild species are being exterminated, and most of them are being reduced in numbers. For man must carry with him the few domesticated species on which his livelihood depends, and wherever he spreads, the native population of the earth must be annihilated to make room for his fields and stock pens. The pressure for room has often been felt in "congested districts" throughout human history. Every triumph of science over plague or famine or other casualty increases the pressure, so long as the excessive rate of increase continues.

The ideal condition of society is that toward which nature points the way in the series of phenomena that we have been studying: the adjustment permitting the normal well-conditioned development of every individual.

There are biological aspects of our civilization that are not reassuring:

(1) The possibilities of the germ are realized only in the individual. Whatever the nature of it, only nurture can bring it to perfection; and nurture is still largely wasted among us in broken lives.

(2) The weaklings of our race under existing conditions, not only survive, but they usually survive to perpetuate their weaknesses in descendants.

(3) There are processes of civilization that select the best for elimination; wars, which kill off the strong and the

brave on the battlefield and leave the weak at home to breed and perpetuate their own weaknesses. Also, there are economic conditions that take the brightest of the children of the poor from their studies and their play, and set them prematurely at grinding toil, thus hindering their normal development.

(4) The excess of offspring is mainly coming from the lower ranks of human society. Those classes that are most advanced in arts and education are hardly reproducing themselves, while the earth is being overpopulated by the descendants of the less progressive. That the educated classes are not taking a larger share in the building of the future race is not in itself a necessary evil, for education is not always an accompaniment of either physical or moral fitness. Indolence and self gratification and the cultivation of low desires breed degeneracy in rich and poor alike. That the population of the earth in the immediate future will be composed mainly of the sons and daughters of poor and ignorant parents is not so serious a matter as it might at first appear; for, with normal aspirations, property and education may be acquired, and the lack of these things may be due to accidents of birth and station. But the danger of qualitative degeneration lies in the rapid and as yet almost unrestricted breeding of the physically, mentally and morally degenerate.

We may get an idea of the possible effect of this differential birth rate on the make up of a population by contrasting the extremes of wealth and poverty as they have been revealed by surveys in some of our industrial cities. Supposing that the rich and educated native population outnumbers the poor and ignorant foreign born in the ratio of 27 to 1: and that the first is diminishing by one third in each generation while the second is doubling. The result would be as follows:

Initial ratio of the first group to the second, 27 to 1
After one generation, 18 to 2
After two generations, 12 to 4
After three generations, 8 to 8

Equality in numbers after three generations! This rate, of course, will not obtain; for the classes are not distinct and separate, and ours is a land of opportunity. With education the children of the poor foreigner will not remain poor and ignorant. However, a comparison of family names by decades in the directories of any of our New England cities will show vast changes in the proportions of those from different homelands across the sea. These changes are due in part to migration, but in a large part also, to differential increase rate.

The greatest problems of man's future upon the earth are connected with better breeding and better nurture. Security for the future undoubtedly lies in having more knowledge, and in making such use of it as will yield better results in racial improvement and in individual development.

## II. The Natural History of Man

Man in the organization of his body is a vertebrate animal. So great is his likeness in structure to other vertebrates, we should have no trouble identifying every organ in his body from the study of the organs of the others. The functions of the parts, too, are so similar that our knowledge of human physiology has largely been derived from the study of other vertebrates. But the slight physical differences existing between man and even the highest mammals are accompanied by vast mental differences.

We will not here review the phylogenetic history of the human body; its development from an egg, its segmentation,

FIG. 169. The Orang (after Bos).

its development of gill clefts, and a fish-like circulation that is subsequently altered to the mammalian type, its nurture through embryonic membranes, its birth, like that of any

other mammal. These do not need to be repeated. And we will only remark in passing that man's nearest zoölogical allies are found among the anthropoid apes. The mammalian order Bimana (two handed animals), which a distinguished zoölogist of a past generation once erected as a pigeon-hole in which man might be kept apart from the higher apes (Quadrumana; four handed animals), has long been merged in the great mammalian order Primates, which includes, besides man and the apes, also the monkeys and the lemurs. The zoölogical differences between man and the higher apes, such as the orang, the chimpanzee and the gorilla, are far less than the differences between these and the lemurs.

**Distinguishing human characters.** — The chief features of man's body that distinguish him from his nearest allies are precisely those that have favored his great psychic development; his erect attitude, his hand and his brain.

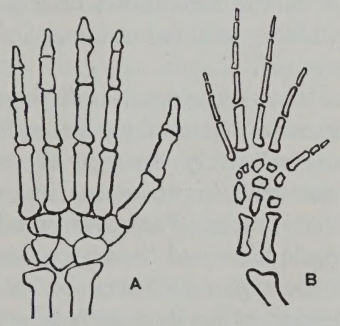



FIG. 170. Bones of human hand and front foot of salamander.

Man is the only mammal that stands erect. His legs are longer and stronger and his pelvic bones are stouter and better consolidated together for bearing the entire weight of the body. His arms are shorter and have more freedom of motion at the wrist, and his cranium is better balanced at the top of the vertebral column than in the apes. These (fig. 169) shuffle along, using the arms as well as the legs for locomotion. The chief advantage of the erect attitude is that it sets the hands free for other uses.

The human hand is generalized in structure; its skeleton

is very like that of the foot of a salamander and not far removed from that of the typical vertebrate (fig. 170). It is much like the ape's hand in its opposable thumb and its freedom of rotation at the wrist. These two features make it adaptable to a great variety of uses. Its readiness at grasping and turning make it a splendid servant of the brain; for it can be used in examining objects, in exploring surfaces and in moving things about. Thus things may be known as objects, and not as mere obtruding features of the general environment. It is hardly conceivable that the specialized hand of a bird or of a fish could be of much use in the educating of its possessor; the variety of sense impressions it could furnish would be very limited. Doubtless the possession of so adaptable a grasping organ has been a large factor in human development. It has made man a tool-using animal. It is the recognition of this service that has made hand-training (manual training) an integral part of our educational system.

The human brain is distinguished by a very great development of the cerebral hemispheres. These, as we have seen, are relatively small in the salamander. They increase in size with improvement in mental power in all the higher vertebrates. They overspread first the olfactory and then the optic lobes and the upper side of the cerebellum, and in the higher mammals their cortex becomes thrown into folds increasing thus its superficial area. They reach their maximum development in the human species, exceeding many times in weight all other parts of the nervous system put together.

The hemispheres constitute, as we have seen, the chief control center of the vertebrate nervous system. This added mass of nervous matter, which was not, in the beginning of development, necessary to the organism, and which is still unconcerned with the ordinary performance of the most

vital processes of the body (although connected with all), may be conceived of as containing innumerable possible nerve paths, formed by the association together of its exceedingly complicated cell-arborisations. In them are possible channels of intercommunication in number far and away beyond the needs of an organism for the performance of the acts that are connected with the inherited instincts of the species. The potential nerve paths of the brain are at first of equal resistance; through them sense perceptions may find their way and responses may wear their channels until all the main highways become estabished in experience.

The external world rains down its innumerable stimuli upon the organism. Those stimuli that are related to experience have the right of way, and determine action. The experiences that accompany action produce effects that are retained in the organism to augment or modify or inhibit further action. Discrimination between stimuli improves with the varying of experience. Discernment of the relation between cause and effect follows, and this may determine choice of action; at first the choice is based on the expected immediate good or ill results; later, on the more far-reaching consequences of the act. Morality comes in here.

In both body and brain man is at birth far more poorly equipped for the struggle for existence than any other animal. He has no defensive armor to ward off attacks of enemies. He has no formidable bodily weapons, teeth, fangs, claws or horns, to make them fear him. He has no equipment of inherited behavior sufficient to insure his safety. His new-born spontaneity of movement is confined to two acts, both of which are directed toward self-preservation and not toward defense; these are sucking and grasping. He has, however, a brain, that, when rightly developed, is

capable of supplying all these deficiencies. And he has a long period of infancy — far longer than that of any other animal — during which to develop it. Relieved by parental care from the necessity of immediately entering upon the struggle for existence, he has time to learn, to feel and to do, to discriminate and to act, to sift and to try an endless variety of experiences and to learn both wisdom and discretion. Infancy, although it be playtime, is in man and animals alike, a time of preparation for the serious business of life. Play is but practice for the game of life.

**Language.** — Man is the only animal that talks. Birds chatter and sing; insects chirp and hum; fiddler crabs gesticulate, and dogs have many ways, familiar to every one, of expressing their feelings; and the rudiments of language are doubtless in the signs and calls which are a part of the social habits of animals. "Actions speak louder than words." By many sense impressions of an object or an act man may gain a conception of its qualities, and then he is able to conceive of the qualities severally, and apart from the thing possessing or manifesting them. From seeing swiftly moving objects, he may conceive of swiftness in the abstract, and then he may use a word to symbolize that conception. Whether a dog or any other animal may conceive of swiftness apart from a swiftly moving object seems highly improbable.

The first words used may have been such calls to companions as two persons unacquainted with each other's language, might today agree upon. Or, they might well have been vocal signals such as men use when acting in companies to secure coöperation. "All together — hee-o!" is such a combination of words and verbal rudiments as we often hear on the streets, spoken by the leader of a group of laborers. The efficiency of such symbols depends upon their being understood; there must be general acquiescence in their use.

How words, as condensed and convenient symbols of experience, have aided mental development was well expressed by Professor Starling, as follows:

"A word is a fairly simple motor act, and produces a correspondingly simple sensory impression. Every word, however, is a shorthand expression of a vast sum of experience, and by using words as counters it becomes possible to increase enormously the power of the nervous system to deal with its own experience. Education now involves the learning of these counters and of their significance in sense experience; and the reactions of the highest animal, man, are for the most part carried out in response to words, and are governed by past education of the experience-content involved in each word."

Without language one may profit by the experience of others only to the extent that he is an observer of that experience; but experience symbolized in words may be dissociated from the individual and told abroad.

**Tool using.** — Man is the only animal that uses tools. Even so simple an idea as the using of a club for defense appears not to have emerged in the mind of any animal. Man, however, had both more need to supplement his weak powers, and more range for adaptive action provided in the accessory circuits of his brain.

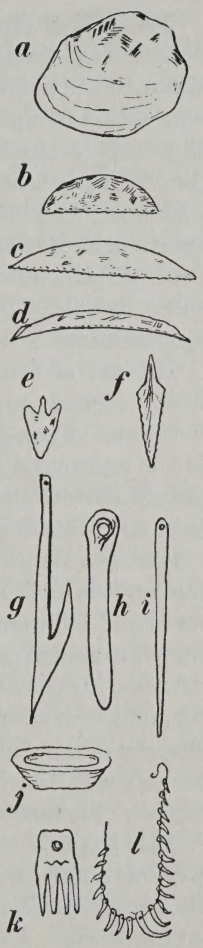



FIG. 171. Primitive tools. *a*, a chipped flint of very ancient form. *b*, *c*, *d*, flint knives of improved design. *e*, a flint arrow head. *f*, a flint spear head. *g*, a bone fish hook. *h*, *i*, bone needles. *j*, a wooden bowl. *k*, a wooden comb. *l*, a necklace of teeth and claws.

The earliest human tools were very simple; a club, a flint stone; such things as might be selected from nature already fitted to the hand. Better tools followed when a little labor was added to their preparation. A split stick lashed to the flint gave a stone ax; and splitting and sharpening of the flint yielded stone knives. A great variety of tools of stone and wood and bone and horn followed; and, later, tools of bronze and of iron. Indeed, the kinds of tools mankind has used furnish a fair index of the progress of the race. Cutting tools especially have been made the basis of ethnological classifications.

**The use of fire.** — Man is the only animal that uses fire. Many animals undoubtedly enjoy the glow of its warmth; and some of our domesticated animals appear to be sensible of the improvement it makes in the cooking of food. But no animal has attained to the idea of adding a stick of wood to keep a fire burning.

Fire was the first of nature's resources to be pressed into human service. Its use appears to have been known to all races and tribes of mankind, throughout human history. It served primeval man in many ways. It increased his physical comfort. It bettered his rough food. It warded off the beasts by night. It aided in the preparation of his crude tools — the shaping of his club and spear, the splitting of his flints, etc. It hollowed the log that was thereby transformed into a canoe — his first conveyance.

The physical comfort of the fireside glow man shares with his animal friends; he differs from them in the foresight that anticipates future needs, and provides the means to gratify them. Even with all our modern improvements in heating appliances we cling to the open blaze with a love that is born of primeval experience.

The use of fire for cooking may have been first learned by

the accidental discovery of the greater palatability of flesh or of tubers that had been roasted in wild fires. Doubtless the earliest modes of cooking were roasting over the open fire and roasting in hot ashes. Water was first heated for the boiling of food by the addition of hot stones to the vessels containing it; it is still so heated by certain North American Indians. The earliest water vessels were shells, as of cocoa-nut or gourd, and the crania of vanquished enemies; and the boiling of food over a fire had to wait on the invention of fire-proof vessels. The first of these were earthen vessels, which were later succeeded by pots of bronze and of iron.

## III. Unwritten Human History

The sources of our knowledge of the evolution of the human species are the three "great historical documents" already familiar; palæontology, phylogeny and ontogeny; but for these as applied to man there are special names to be used. There is in the case of men and animals an actual record of the past, incomplete but indisputable. It is preserved in the bones and teeth and armor of animals and its study is known as palæontology. It is preserved in the weapons and defenses that man has substituted for fangs and claws and armor, and in the imperishable products of his hands, and its study is known as *archæology*. There is also the same opportunity for comparative study of developmental attainments in men and animals, and for arranging genetic series and deducing history therefrom; for different races of men exist in very different cultural stages. The study of these is called *ethnology*. The development of the individual is of some historical value also even here, for the corroborative evidence that it may furnish.

**Archæology.** — Written history goes back but a few thousand years, but the records of archæology extend back hundreds of thousands of years further. The oldest extensive series of human remains have been found in the interglacial deposits of the ice age. These consist of man's own skeleton, his tools and the charred remnants and ashes from his fires. They are found mainly in caves, associated with the bones of cave-dwelling animals. The extinct cave bear and the mammoth were his contemporaries, the former being his competitor for such shelter as caves afforded. His tools at this period were few, and of the simplest sort; chipped flints, a club, a sharpened bone, etc.

The objects of his home environment were such as bestrew the lair of the wild beast in similar situations — chiefly the remains of his feasts, the most imperishable things being the bones of his victims. Among these are found human bones, split ingeniously for the ready extraction of the marrow — a choice morsel of his diet. It is not an attractive picture of the life he lived that these facts suggest. It differed from that of the cave-dwelling beasts chiefly in the use he made of tools and of fire. There is a faint promise of his later attainments in the marks of scanty workmanship found upon his tools.

We cannot go into the fascinating story that is written in the remains of later date; the slight changes of his skeleton, and increase of cranial capacity; the improvement and diversification of his tools of flint and wood and bone during the Age of Stone (when the use of metals was as yet unknown); the development of implements, and of articles for personal adornment, and the beginnings of art; the vast changes in his material equipment during the succeeding ages of bronze and of iron. No written account of these records of human progress can be equal in value to a thought-

ful visit to any good museum of antiquities, in which the archæological exhibits are arranged in evolutionary sequence. The cruder materials with which archæology deals, although much neglected in the past, have come to be appreciated as among the rarest of human treasures.

**Ethnology.** — As amœbas continue to exist on the earth along with men, so savagery and all intermediate conditions persist, along with the most modern types of civilization. And as the primitive forms of life are restricted to the places that are left unoccupied by the dominant types, so the more primitive types of culture are relegated to the out-of-the-way places of the earth. Comparative ethnology, therefore, has had the same kind of opportunities as comparative anatomy, and has made use of them with similar results; i. e., cultural types have been described and classified. Similarly, also, the different systems of classification have not always been in agreement. A simple grouping based on the main features of men's methods of getting a living from the earth, will answer our present purpose. It recognizes four principal stages in human progress: (1) the hunter stage; (2) the shepherd stage; (3) the artisan stage, and (4) the inventor stage.

FIG. 172. Man.

1. The earliest of these is the *hunter stage*. It comprises

that long period during which primitive man lived upon the products of nature, lived as a freebooter, picking from the wild, cultivating nothing for food. He was less provident than the squirrel or the ant, and far less industrious. He was satisfied when present needs were met, and accumulated nothing. He built only the rudest shelter, at the first wore no clothing, and had no society. His food was, doubtless, not very different from that of the cave bear, with which he was a competitor; the flesh of animals and the fruits and roots of plants; perhaps, also, and an occasional feast of wild honey. His early home was by the waterside, and fish were a most dependable part of his living. Fish he could catch by hand, or, better, with a bone hook, or with a spear. It was easier to spear fish from a floating log, and a hollowed log with a pole for propulsion was probably his earliest conveyance. Larger canoes demanded more hands to propel them: and in the propelling of these, and in the driving of the fish upon the shoals may have begun coöperative labor. Cereal grains, especially rice and barley, early became important food stuffs, and with the stone mortar for grinding grains household arts may be said to have begun.

FIG. 173. Coöperation.

2. The *pastoral stage* is ushered in with the beginning of the domestication of animals and the cultivation of plants. When man tamed the wild things, some of them rewarded his care by furnishing him with a larger and more dependable food supply. Thus foresight grew, and agriculture began. The possession of fields and folds made for settled homes and for social organization. An abundant food supply could support a larger population. The history of nations begins here.

The first agricultural implements were crude enough. The first mill was a stone mortar; the first plow was a crooked stick, the first apparatus for weaving of fibers or hair into cloth was a wooden shuttle. With better food supply, less time was required for obtaining a livelihood and the energies thus set free were available in some measure to be devoted to the perfecting of the finish of manufactured products and the development of the fine arts.

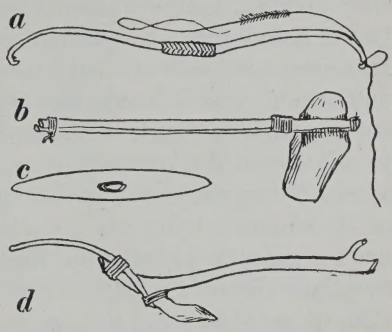



FIG. 174. Primitive implements. *a*, a bow (California Indians). *b*, a stone ax, with split wood handle. *c*, a wooden shuttle. *d*, a wooden plow.

3. The *artisan stage* naturally followed upon the development of increased food supplies; for exchange of products began, and commerce demanded wheels and keels. Improved tools of metal were needed, and artisans, of various sorts, to use them. Money came to be used as a medium of exchange, replacing the barter of products that was characteristic of the pastoral stage. Men began to gather into cities. In preceding stages all men were engaged in much the same pursuits, but now they differentiated, one man producing articles for the use of the others, and receiving the products of the others in exchange.

4. Finally, came the *inventor stage*. The forces of nature were harnessed to do men's work. Artisans largely gave place to operators of machines. Production was vastly increased; population grew apace. The exigencies of commerce demand the centralization of lines of communication and of

transportation and thus cities grow. And the end of this is not yet.

Doubtless the earliest of these periods was most extensive; the night of savagery was long and the dawn broke slowly. But it was a period of physical perfecting, and of sound beginnings of mental improvement. During the long struggle with animals, better equipped by nature for fighting, man had to match their strength and cunning with his wit. Thus he gained good eyes and ears, a supple frame, quick muscles and strong sinews, hands that could control weapons with deftness and, precision, and, above all, a brain that could turn to advantage the circumstances of his environment. The elimination of the unfit was then most rigorous. The savages of all dominant tribes are fine physical specimens, and it is not too much to say that on this basis of physical fitness all subsequent history is built. The foresight that would put a stick of wood on a fire to keep it going, that would shape a stone for hitting, or that would improve its efficiency by the addition of a handle, marked an enormous psychological departure from the status of the brute. The native taste that shaped an arrow head with symmetry and beauty, or that traced with flint its crude fancy in a picture on bone, had in it the germ of art. Given these and language, all subsequent history was possible.

**Ontogeny.** — From birth onward the developmental phases in man do not help greatly with the unravelling of his history, for they are much altered by environmental influences. But there are many things that are suggestive of a sort of correspondence with phylogeny. The infant is born with hands that are fitted for grasping, and capable of sustaining his weight. When he begins to travel he goes on " all fours," and it is not until he assumes the erect position on his feet that he advances in action beyond his four-footed relatives.

Relieved of the function of support, his arms learn throwing and striking and pulling. He imitates all sorts of movements, and engages endlessly in play that is imitative of the work of his elders, and that is essentially like the play of other young mammals. At about the age of twelve he appears to arrive

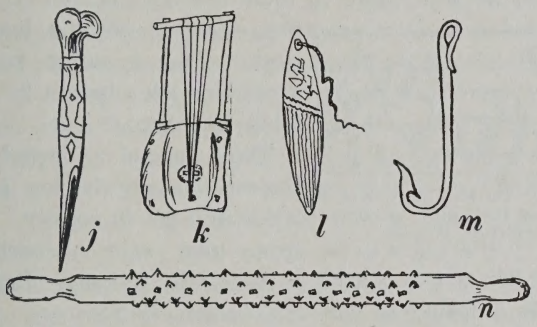



FIG. 175. The beginnings of the arts. *j*, a carved dagger made from a human bone. *k*, a stringed instrument (Upper Nile). *l*, an instrument to be used against evil spirits (S. Australia). *m*, a bronze fish hook (Lake-dwellers of Switzerland). *n*, an instrument for correcting heterodox opinion, (known as a "spiked roller"; the infidel was usually stretched naked upon a rack and rolled vigorously with this instrument as a means of correcting his beliefs: Germany; Middle Ages). (All after Brinton.)

at consciousness that he is a part of a community; for he begins to play with his fellows at coöperative games and organized sports; he enters upon team work.

Ethnic culture stages are rapidly passed through in the experience of his earliest years. At the beginning he is a freebooter, taking what he likes of what he sees, recognizing no rights of property, and doing nothing to produce what he consumes. Then he enters upon the domestication of animals and the cultivation of plants quite naturally and on his own account. He cultivates the good will of his pets and feeds them, and makes them work for him. He plants flowers and vegetables and clearly recognizes ownership in

these things. Then he comes to be interested most keenly in tools and in the things he can make with them. At this age he is vastly more benefited by the gift of a jackknife or a hammer than of more complicated toys. An Indian's bow and arrow is more to be desired than a repeating shotgun. But soon he will aspire to have the complicated toys and the engines and the hand organs. The inventor stage is upon him even before he is entered in school.

FIG. 176. Threshing scene. From a painting on the wall of an ancient Egyptian tomb (after Brinton).

**The social organism.** — Human history begins in isolation and not in society. Primitive man was a barbarian, and the life of a barbarian is essentially solitary. Probably he made a friend of his dog earlier than of any person outside his own household; for strangers were enemies. And the reason for this is not far to seek. He must have room, or starve. He could not live on grass or any other plant product of unlimited abundance, as do the mammals, that nature had made gregarious; nor had he superior powers of locomotion that would enable him to get about and find widely scattered food products as do the social birds. The households of cave dwellers were, therefore, few and far between.[1]

Nor are the habits of a barbarian favorable to social life. He eats like an animal when hungry, and waits until hungry again before setting out to find more food. He is quarrelsome when hungry and lazy when fed, and, being perfectly satisfied with himself, lacks the mainspring of progress.

[1] Ethnologists estimate that without any agriculture, it requires sixteen square miles of territory in temperate regions to furnish sufficient available food for one person.

FIG. 177. Coördination.

The narrow sympathy that in primitive man was born of his parental and conjugal instincts, and that was limited to his family, may have been widened through his dealings with animals when he had domesticated them. The man who will bind up the broken leg of his dog, or pull his ox out of a ditch is more likely to help his fellow man when found in distress. Tolerance of fellow men led to the formation of tribes, which at first were composed of a few allied families. Primitive tribes retain the characters of the individual barbarian; they kill outsiders, and often eat them, and not infrequently they similarly dispose of a part of their own female infants, in order to keep the birth rate down; the tribe, also, must have room. Tribal societies are ever at war; and wars, besides preventing increase, block progress, destroy property, and curtail desire to do or to build. The beasts were man's first enemies, but since he learned to make efficient fighting weapons, his own kind have been his worst enemies.

The growth of nations may be said to begin with the cultivation of plants in fields. This made for settled homes, for the establishment of property rights, and of law and order (within narrow limits), for the development of knowledge, and for the accumulation of the means of livelihood that should set men's hands free to do something besides meeting the needs of the hour, and their minds free to forecast future needs. Unfortunately these needs were too largely needs of defence against other nations. For, in the beginning the

savage characteristics of their constituent tribes were passed on to the new-formed nation. Nations initiate wars to annihilate other nations. Most of the migrations of the human race have been migrations of conquest. Hence, the earlier civilizations of the earth could only grow where a nation could exist in comparative isolation. Such places were the desert-bordered valley of the Nile in Egypt, the mountain-fringed table-lands of Mexico and Peru, etc. They did not grow in the earth's exposed areas, such as the Mississippi Valley, although the works of the mound-builders show that great constructive efforts once started there. There was security only in isolation until the growth of a broader sympathy and the dawn of a more constructive social spirit.

Socially, primitive man was unspecialized. Aside from differences of the sexes, there was nothing preformed in his bodily organization determining what should be his relations to other individuals of his kind. There was no preformed division of labor as in bees; there were no castes, as in the ants and the termites. He came into possession of no particular modes of social activity by inheritance. If he attained to social coöperation he had to acquire it for himself. But he possessed speech; and speech wondrously facilitated coöperation and the exchange of experience and the comparison of old ways and the development of new ones, and conditioned further development. And he possessed laughter — a fountain of social responsiveness, and a means of extending sympathy and developing comradeship surpassing speech. And the primary demand of social progress is sympathy, and good will toward men.

**Animism.** — Animals live in a world of sense perception, but man has always lived to a greater or less extent, in a super-sensual world — a world of ideas. In language man crystallized his concepts and gave them currency. They

were concepts first of the things he saw and then of their properties; also, of the things he imagined and then of their imagined properties. Having attained to a discernment of the relation between cause and effect, his mind demanded explanations of the things in the world. Any explanations were better than none. When he had gained ascendency over the powers of the animal world and, by the establishment of the rudiments of agriculture and household arts, had forefended himself against immediate want, he took to thinking: the great problems of birth and death, of times and seasons, and of the heaven and the earth were before him.

He was interested in the relation between his own body and the breath or spirit that animates it; and out of the consideration of this problem, he evolved ideas that, more than any other, have dominated all the intratribal social intercourse of subsequent history. He conceived of a spirit of like form with the body but impalpable and separable from the body, that goes a-wandering from it in dreams and trances, but returns again; and that leaves the body at death to wander elsewhere as a disembodied spirit, or to take up a new abode. He conceived that animals also possess kindred spirits and he wore the teeth and claws of ferocious beasts in the belief that thus he assumed their powers. His imagination peopled the world with spirits; mostly evil ones, with fearful powers for harm, demanding to be propitiated by sacrifices, offerings or worship, or controlled by magic. These spirits might enter into human bodies, producing demoniacal possession, witchcraft, disease, or death. This, in brief, is animism. It appears to have been the earliest form of both philosophy and religion of all savage tribes. It has practically no moral purpose or effect. It appeals mainly to men's fears; for although it peoples the

world with both good and evil spirits, the evil ones are mainly worshipped, because fear is a more powerful emotion than reverence.

Some of the specialized manifestations of animism are, (1) Spiritism, the belief in the existence of free spirits: ghosts, etc. (2) Fetishism, the belief that the spirit resides in an object, which then becomes a *fetish*, and is treasured for the magic power it possesses: charms, etc., such as the rabbit's foot, the old horseshoe, and the four-leaved clover. (3) Magic, the belief that the spirit is controlled (or that some supernatural result is wrought) through the performance of some act. (4) Ancestor worship, the belief in the presence and supernatural power of the good spirits of dead ancestors, etc. A little study of the harmless survivals (psychic vestigial *relicta*) of these things should be convincing that animism has left its permanent records with us, and that these records are of interest and value as landmarks of an evolving culture.

Nowadays we hold magic and charms in so light esteem, that we are apt to overlook the tremendous importance they have had in the past. Our language and literature and history are full of them. Our clothing drips with them, for it grew out of them. Is there not a place for a charm on a watch chain? And what is a locket but a case for some sweet magical thing like a lock of hair, that may be worn next the believer's palpitating heart? Betimes, we lay aside our seriousness and have a little romp of childhood in this intellectual haymow of stored primeval experiences. Especially do we this at holiday seasons, when the emotions rule and when dormant racial instincts waken easily. We hang the mistletoe at Christmas tide, and at Hallow-e'en we indulge in all sorts of absurd divinations. We tell fortunes. We consider signs. We give birth stones. We tell ghost stories

in the dark — the primeval setting, and the condition that stimulates the latent racial emotions which we wish to recall in diluted and enjoyable form.

But these are matters serious enough to many of our own population; witness the advertising columns of the necromancers and magicians in some of the Sunday newspapers. And we do well not to forget with what tyranny such ideas have held sway over our entire race during most of its history. Selfish and vainglorious magicians and sorcerers and healers have been able, through appeals to fear, to practice great oppression, and to add a grievous burden to the sins and miseries of all savage peoples. The earliest records of all races are full of this. Happily, they tell also of prophets and seers who have risen to point out truer relations between cause and effect, and of great leaders who have sought to free men from the bondage of superstition, and of teachers who have labored to dispel ignorance — its cause.

Besides wars and superstitions, there are yet other troubles of his own creation that have vexed man throughout his history. He has never been satisfied with food, but has always and everywhere wanted something added to his diet to excite or modify the action of his nervous system. Opium and alcohol are typical of these; and the use of stimulants and narcotics has added and is still adding enormously to the vast sum of human misery in all nations.

Nor has he ever anywhere been clothed with the utmost possible comfort and convenience. Dress was originally for charm bearing, for ornamentation, or for sign of rank or station; and it is little modified from its traditional functions by considerations of comfort. Every improvement in methods of getting a livelihood that has set men's hands free from constant toil and given time for thought, has made opportunity also for the growth of social habits with-

out thought. In the social organism, as well as in the physical, things have run their course unchecked by environing conditions. Traditions are usually cherished quite irrespective of their usefulness.

FIG. 178. A stylish young Botocudo Indian (Brazil). Psychological orthogenesis. (After Brinton.)

**Social integration.** — Society is first an aggregate and afterwards an integrate of human beings. The social organism has followed the same developmental methods that have perfected the multicellular body, and made of it an integrate organism. Ancient history is filled with endless experiments at social integration. The parts brought together at first lacked the essential bond of mutual dependence. They were alike save for the differentiation of the sexes, and each man, or at least each family, was capable of getting along alone. Differentiation and division of labor was necessary here as in the physical organism to create the need of one part for the complemental parts that should bind all indissolubly together.

Differentiation occurred in strict accordance with the physical needs of men, which are the same as those of animals — needs of food and shelter and defense against enemies. Hence the earliest of callings are those of hunter and fishermen, soldier and scout, shepherd and husbandman, builder and weaver, etc. Precise fitness of any of these callings involved loss of fitness for the others, and made the specialist in one more or less dependent on all the others for that

part of his living that he could not so well provide for himself. The primary condition of social integration is mutual dependence.

Social stability demands coördination. The parts must function harmoniously, so that the actions of any or of all shall be made subservient to the welfare of all. This demands (1) intercommunication between parts, and (2) the development of centers of control. Intercommunication is primarily needed for exchange of products. Therefore, as the physical organism develops circulatory apparatus, so the social organism develops channels of trade. Are they not popularly characterized as "arteries of commerce"? Means of sensory communication are next needed; and as the physical organism develops nerves so the social organism develops postal and telegraphic lines. And do we not hear these fitly spoken of as "nerves of intelligence"? Control centers in the physical organism arise, as we have seen, where nerve cells are gathered together to form ganglia; and similarly in a nation they develop just as naturally wherever those individuals live who assume the function of coördinating and directing the activities of the whole body politic, (councils, directorates, congresses etc.). And are not these also with some propriety often called "centers of trade, of culture, or of government"?

When organization has proceeded to the point of establishing control centers its efficiency depends on the concurrent development of such organs of outlook as are capable of giving knowledge of the outside world, and the maintenance of such mutual responsiveness and adaptability of parts within as will admit appropriate actions in response to the things discerned. The watchman in the tower is as the eye of primitive society; and equally so are the explorer and the investigator in later times. As the body is profited by

its distance receptors, so society is profited by its seers and prophets of truth. It is natural, therefore, that with later specialization, groups of individuals should have been set apart from the ordinary avocations to serve society as watchmen, devoting their energies to scanning the face of nature and to the discovery of the principles of science. The scientific centers are as the eyes of a nation.

But eyes are merely receptors; the effectors or rulers are elsewhere in the body. Given good eyes, fitness of reaction yet depends on the discriminative powers and the capacity for correct coördinated responsiveness of the organism as a whole. It is possible that the worst of actions may follow upon the best of vision. Society is not bound to progress. It may go forward, or it may halt, like a salamander that stands blinking at the light, and then runs back to its hole. So in our own time it seems to be blinking at the question of international peace.

Society makes progress as its constituent units become clear in perception, united and correct in discrimination and inference, and concordant in action. The parts must not only act together (harmony is not all that is necessary); they must act together in profitable ways.

**Social conduct.** — The individual begins life as a single cell, and has first of all to run over in ontogeny a course in phylogenetic history that is enormously long. This, however, is quickly passed. A sound body and well organized animal instincts are his by right of birth. He has yet to retrace the course of human development; and this, though comparatively short, is beset with difficulties; for his art and science he must for himself acquire. Nature will make of him only a barbarian; nurture must make of him a citizen.

He must first of all acquire the methods of education. He begins with trial and error; but this method is too slow,

too uncertain in its results, and too apt to cultivate ways of going elaborately wrong, alongside of those which go right. He must learn to imitate, and must learn by imitation. He must learn to do, or not to do, as others do. By these means he lays a broad basis of personal experience. By these means he is made fit for social intercourse. For so he learns the signs in which racial experience is expressed: gestures and attitudes, manners and customs, and, most of all, words. The circumstances of his nurture compel imitation. Only the same signs that others use will be understood. And by continual imitation he establishes automatic habits like those of other members of society. His social conduct takes on forms that are like to the instincts of animals in their fixity, and he becomes a fit and acceptable member of society. The moral person is he whose acts are in accord with the accepted rules of conduct for the community.

But society is an organism, and therefore adaptable. Just as there are common emotions, ruling as with an iron hand the general conduct of the people, so also there is a common intelligence that may find better modes of action. It may seem at times to exert but little influence. Appeals to instinctive habits always bring tumultuous responses; for racial nerve paths are thoroughly well broken for stimuli to eat, to drink, to fight and to indulgence of the baser passions; and the plea for better things, may often seem to fall on deaf ears. The prophets and seers who have sought to extend public vision may at times seem to have labored in vain. But in the social as in the physical organism, in the long run, intelligence wins.

Trial and error was at first the sole method of progress; but society learned to imitate and has improved by imitation; and it has learned to initate new activities and to inhibit old ones by reason of clearer discernment of the truth. We no

longer piously burn witches, or beat lunatics to drive the devils out of them.

Society, therefore, having taken stock of its experiences, has instituted some integrating forces of its own. Education is the chief of these: universal education; for organic health is impossible unless all the parts of the organism be properly responsive to common needs. Instruction now brings within reach of the individual the best things of racial experience, both past and present; and if there be discernment, practice develops in him the appropriate modes of action.

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